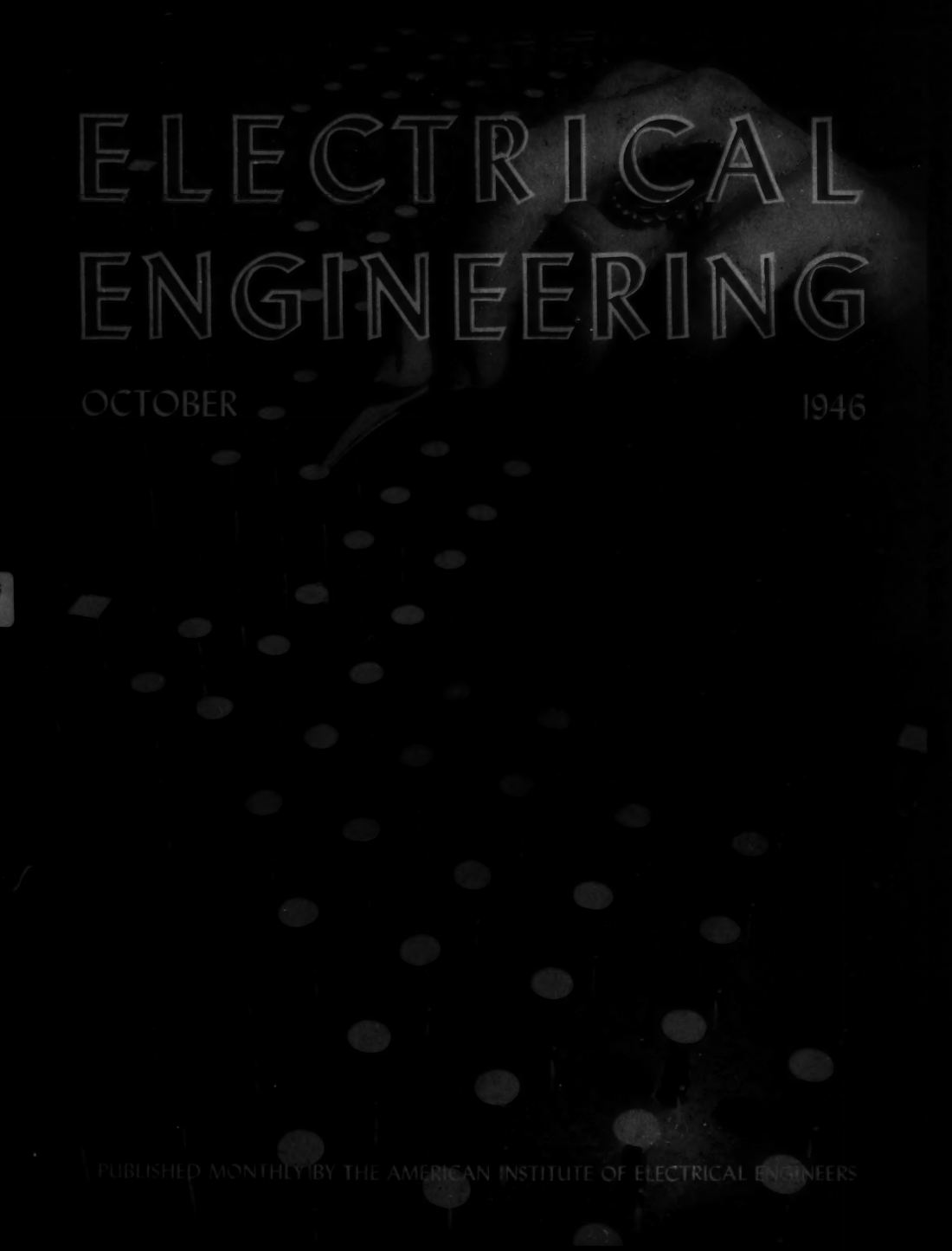
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OCTOBER
1946
PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

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OCTOBER
1946

The Cover: Pool unit of reservoir behavior analyzer used to forecast reservoir pressures. Electrodes may be made to represent wells which are identified by tabs.

Photo courtesy *The Lamp*, Standard Oil Company of New Jersey

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The old world spins faster now . . .
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by visions? You will see them come
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to build your box of magic.

HIGHLIGHTS.....

Pacific Coast Meeting. With an estimated attendance of more than 500, the Pacific Coast meeting was held this year in Seattle, Wash., August 27–30. Full details of the meeting will be reported in *Electrical Engineering* for November.

Japanese Radar. The insistence of Japanese military leaders on keeping army and navy research, development, production, and operation entirely separate, as well as Japan's failure to organize the full scientific power of the nation for war research, probably was largely responsible for her inability to develop effective radar equipment during World War II. This conclusion is reached in Part II of an article based upon an official report prepared by the United States Army (*pages 455–63*).

Lamme Medal Award. The Lamme Medal for 1945 was awarded to David C. Prince (F '26) for his work with high voltage switching equipment and electronic converters. The three addresses delivered during the medal presentation ceremony include some pertinent remarks concerning the donor, Benjamin G. Lamme; an account of the medalist's career; and Doctor Prince's acceptance address in which he acknowledges the inspiration afforded by the inscription on the Lamme Medal, "The engineer views hopefully the hitherto unattainable" (*pages 435–41*).

Statistical Methods. The 11th article in the statistical series discusses the statistical interpretation of limited experimental tests. These "tests of significance," as they generally are called, have proved useful disciplines in experimental development although they often are misused through superficial generalization and enthusiasm (*pages 466–8*).

Unionization of Engineers. Although of the personal opinion that unionization of engineers is an unnatural development, an AIEE Student Member warns the profession that the labor union idea is becoming increasingly widespread among young engineering graduates. He believes that one solution might lie in a more active interest on the part of established engineering societies in the employment difficulties of their members (*pages 445–8*).

Westinghouse Centennial. Since the birth of George Westinghouse 100 years ago the era of rugged individualism in which he was a leader has given way to a period of increasing dependence on planned economy and government control. Technologically and scientifically the intervening years have witnessed much progress, but they also have witnessed a serious undermining of those elements so essential to the continuance of a properly functioning society; namely, individual responsibility, good will, and leadership. If Westinghouse were alive today he surely would agree that progress is attained primarily through individual liberty (*pages 442–5*).

Automatic Calculator. Part II of a 3-part article describes the functions performed by the multiplication and division registers and the functional units of the automatic sequence controlled calculator presented to Harvard University (*pages 449–54*).

Bikini Report. Were the atomic bomb tests at Bikini worth while? What are the general indications for the future? A member of the Institute who witnessed the tests relates his observations, which coincide, in general, with official reports on the subject (*pages 463–5*).

UN Electrical Facilities. Reputed to be the largest continuously louvered ceilings in existence, the ceilings of the two main council chambers of the Lake Success quarters of the United Nations each consume a total of 24 kilowatts for illumination. Each chamber has a general illumination of 58 foot-candles at the center of the room which tapers to 35 foot-candles at the edges (*page 484*).

Electrical Engineering Exposition. An electrical engineering exposition originally planned for 1941 but postponed because of the war will be held in New York concurrently with the AIEE 1947 winter meeting. The exposition will feature the newest developments in electric equipment for the generation, transmission, distribution, and utilization of electric energy (*page 485*).

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Mica Capacitors. Current design of carrier telephone and other communication systems imposes special demands on capacitors used in frequency-sensitive systems. To meet these exacting requirements for capacitance tolerance at the time of manufacture and for subsequent permissible change in capacitance, mica capacitors having sprayed silver electrodes bonded to the mica laminations have been developed to replace former designs (*Transactions pages 670–4*).

Aircraft Engine Synchronism. With increasing emphasis being placed on multiengine airplanes for commercial and military use, it has become more and more important to devise a satisfactory method for synchronizing aircraft engines in order to attain the maximum in comfort and flight efficiency, and visual synchronism seems to meet the requirements. This method employs an instrument which indicates the degree of synchronism between two engines by measuring the frequency difference between the outputs of the generators connected to each engine (*Transactions pages 650–3*).

Current Ratings for Wire and Cable. There is no accepted standard method for determining the short-time current rating of wires. However, based upon a comparison of the results of the three methods generally used by engineers—thermocouple, oscillograph, or voltmeter-ammeter—a current-time-temperature test is recommended which utilizes a voltmeter-ammeter for times down to five seconds and an oscillograph for shorter times (*Transactions pages 644–8*).

Servomechanism Analysis. The mechanical transients analyzer provides a fast and simple method of obtaining complete solutions of the performance equations of servomechanisms under any type of operating condition. Solutions based on data obtained from a general study of variable-voltage angular-position servomechanisms include system frequencies and per cent damping per cycle that are applicable to any system disturbance (*Transactions pages 636–9*).

Ignitrons. Because the auxiliaries required for excitation and temperature control are an important part of the rectifier unit, the successful design of this unit must allow for the characteristics, limitations, and requirements of the electron tube. Among the factors which must be included in application data for mercury pool tubes or tanks are their excitation, control, and cooling characteristics (*Transactions pages 632–5*).

Politics. AIEE member Victor Wichum is a candidate for Congress from the 10th Congressional District, Kings County (*page 492*).

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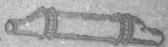
The Oilostatic Transmission System requires only these steps: . . . digging a narrow trench . . . placing in it a welded steel pipe . . . pulling in solid type paper-insulated cable . . . then connecting easily-made joints and potheads  . . . installing a prefabricated pumping unit and reservoir . . . applying 200 lbs. oil pressure for operation up to 230,000 volts.

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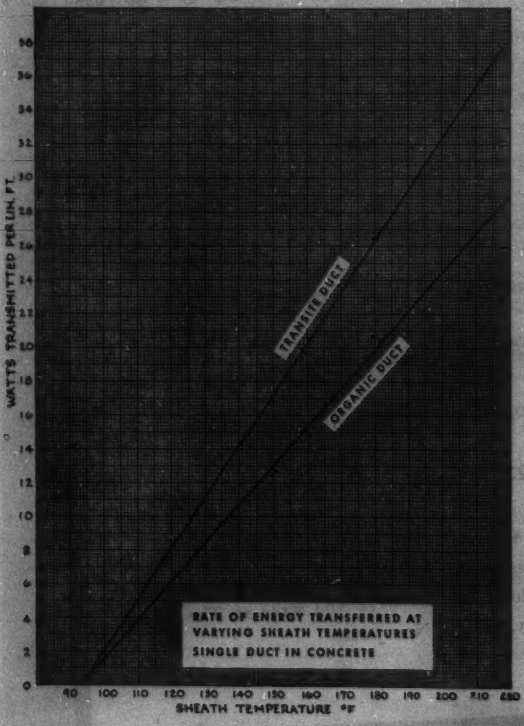
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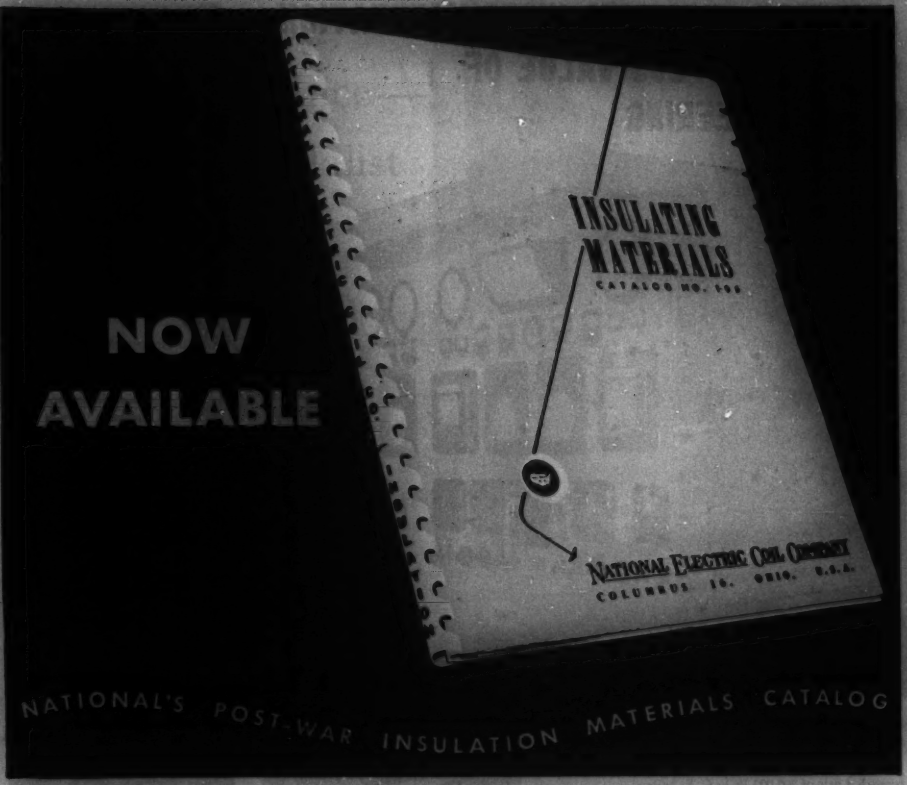

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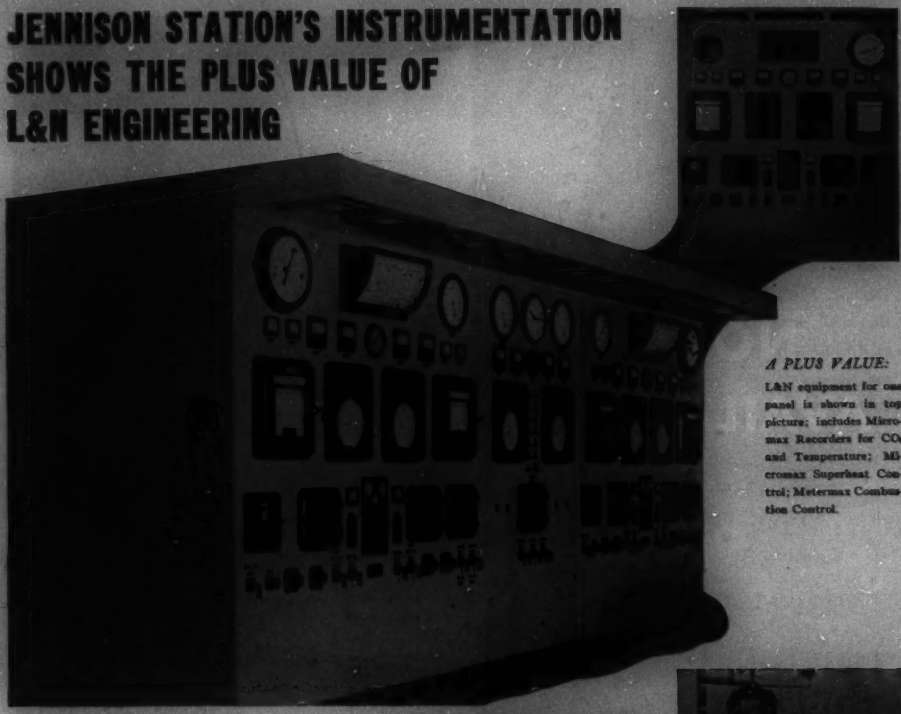

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Jrl Ad N-169(15)

David C. Prince—Lamme Medalist

The 18th annual presentation of the Lamme Medal took place at the recent AIEE summer convention in Detroit, Mich. The 1945 medal was awarded to David C. Prince (F '26) "for his distinguished work in the development of high voltage switching equipment and electronic converters." The award is made each year to an engineer "who has shown meritorious achievement in the development of electrical apparatus or machinery."

Photo courtesy Electrical Contracting

AIEE President William C. Wickenden (F '35) (left) presents the Lamme Medal to Past-President David C. Prince (F '26)

The Lamme Medal

C. M. LAFFOON
FELLOW AIEE

THE FIRST LAMME MEDAL Award was made in 1928 and similar annual awards have been made since that time. The medal award ceremony this year thus was for the 18th recipient of this outstanding honor.

In previous years the biography of the donor, the conditions and circumstances associated with the provisions for the award, and the terms of the award have been presented by others in considerable detail, and so need not be repeated here. It, however, seems appropriate to add, if not to repeat, the fact that Mr. Lamme was fundamentally a design and development engineer throughout his entire engineering career. His heart and soul were wrapped up completely in electrical engineering design problems. He was not interested in the executive phase of engineering and did not function in that capacity as chief engineer of the Westinghouse Electric Corporation.

He felt very strongly that design engineers needed, not only encouragement and inspiration, but also recognition by the engineering profession for outstanding ability and achievement. It was primarily for this reason that the bequest for this medal award was made.

There are many conditions associated with, and characteristics of, Benjamin G. Lamme, the man, that are unusual and interesting. He was a firm believer in the theory that a person's inherent aptitude for a particular type of engineering work would manifest itself at an early age. If one, during childhood, enjoyed finding ways and means of building toys and structural things he had the earmarks of a designer. On the other hand, if he liked most to make things run or perform, he had natural instincts toward application or operating engineering. This working theory was used by him for many years in selecting candidates from engineering college graduates for special design training. He never was disturbed by the fact that an occasional design school candidate would misrepresent his early aptitudes; for invariably the truth would be self-revealed and the person finally directed to some more suitable activity.

The imagination and enthusiasm so strongly associated with Mr. Lamme's engineering work were also evident in his outside activities. He had an intense passion for reading weird and imaginative fiction for relaxation purposes. An around-the-world trip was made to see and examine at close hand the famous historical buildings and structures in Africa, Asia, and Europe. As a personal pleasure he particularly enjoyed owning and driving high-powered reliable cars at rather high speeds.

C. M. Laffoon is manager, a-c generator engineering department, Westinghouse Electric Corporation, East Pittsburgh, Pa.

An address delivered during the Lamme Medal presentation ceremony at the AIEE summer convention, Detroit, Mich., June 24–28, 1946.

As might be anticipated from one so completely devoted to his engineering work, Mr. Lamme never was married. On a number of occasions he, half-jokingly, and possibly in self-defense, remarked that an engineer did not have time to be an engineer and to carry on the responsibilities of a family. Although Mr. Lamme was always friendly and extremely considerate of people, he maintained close social contacts with only a very small number of persons. He took great delight in unobtrusively discussing engineering problems with, and thus obtaining the viewpoint of, the nontechnical people with whom he occasionally came in contact.

As time moves on it is to be expected that many of the events, facts, and conditions connected with Mr. Lamme's life will assume different significance, and his engineering contributions greater importance. In the Lamme Medal presentation we not only bestow recognition on one of our own present outstanding engineers, but also pay our respects, tribute, and honor to the memory of one of our truly great pioneer engineers.

The Medalist's Career

H. E. STRANG
FELLOW AIEE

The 1945 Lamme Medalist, David C. Prince, is first and foremost an inventer with 93 patents to his credit covering subjects ranging from electric ship propulsion to welding circuits. A consistent breaker of tradition, he is one of those who have the ability and imagination to think in terms of progress in broad steps regardless of the seeming insurmountability of the problems confronting them. He is considered an ideal choice for the medal which symbolizes the engineer's hopeful attitude toward the seemingly unattainable.

IF WE COULD look back on a scene in Springfield, Ill., on a day early in this century, we might see Doctor Prince, a successful surgeon, and his son David going about in a single cylinder Oldsmobile as the doctor made his calls. The boy was as full of questions as most normal youngsters of that age. In response to the searching "Why is this so?" he got not only specific answers from his father, who was an inventer in his own field, but also encouragement to extend his thinking and questioning along new and unexplored lines. Through this association was built the foundation for new and creative thinking which characterizes David Chandler Prince and which has led to the high honor of the award of the Lamme Medal.

It was quite natural for Doctor Prince to hope that David would follow in his footsteps in the medical field, and so, after graduation from the Springfield High School in 1908, David entered the premedical course at the University of Michigan. After a year and a half of this course, during which time he had been studying engineering just as a hobby, he persuaded his father that engineering, and not medicine, was really his proper field. The next year David transferred to the University of Illinois so that he might spend his last two undergraduate years studying under Doctor E. J. Berg, professor of electrical engineering, and former assistant to Doctor Steinmetz in the General Electric Company. David then was certain that he was on the right track. Doctor Berg thought so, too, and years later said of him, "I never knew anyone else who had the keenness of mind and understanding of Prince."

Following graduation, and at Doctor Berg's suggestion, Prince obtained a summer job in the General Electric Company's service shop in Chicago to round out his technical training with some practical field experience. He then returned to the university for a master-of-science degree, and, with this to his credit, set out for Schenectady, N. Y. After a typical experience on "test," mostly spent working on motors and generators, Prince acquired an ambition to become associated with Doctor E. F. W. Alexanderson in the transportation engineering department. The first World War soon interfered, however, and shortly after the United States entered, Prince enlisted and was shipped overseas as a first lieutenant in the United States Army Ordnance Department. His two years in France were, from his standpoint, educational and enjoyable. Attached to the air service, he was given the task of installing guns on airplanes purchased by the United States from the French, and even though he occasionally had to go "AWOL" to do it, he completed the task. For this work he received from Washington, at the close of his military career, a citation "for especially meritorious service in the solution of engineering problems relating to aircraft." He still keeps on his desk, as a paperweight, a jagged chunk of metal from a Big Bertha shell which landed not far from him on a street in Paris.

After the war, Prince returned to Schenectady just in time to hear that a patent had been granted on "certain new and useful improvements in speed control of induction motors." This was his first patented invention—the product of his earlier work with Doctor Alexanderson, whose name also appears on the patent. As he resumed work—first with Alexanderson, next in the radio engineering department, then on a part-time job

H. E. Strang is staff assistant to manager of engineering, apparatus department, General Electric Company, Schenectady, N. Y.

An address delivered during the Lamme Medal presentation ceremony at the AIEE summer convention, Detroit, Mich., June 24–28, 1946.

with Alexanderson in the new Radio Corporation of America—he literally began to pour out inventions. At the present time, his patent score stands at 93. These cover an amazing range of subjects—electric ship propulsion, a-c locomotives, circuit breakers, protective relays, welding circuits, vacuum switches.

Many men, both within and outside the General Electric Company, have more patents to their credit than Prince. Few, however, have worked out so many usable ideas. His fundamental improvements in electronic tube circuit control have broadened the scope of resistance welding and thus directly improved mass production of refrigerators, railway cars, and airplanes.

Prince worked with Alexanderson until 1923 when he was transferred to the research laboratory. He spent months in the study of electronic theory, which at that time was a new subject on which very little was written, and was busy for several years on vacuum tube application. He was selected by Doctor Whitney, head of the research laboratory, to attend an AIEE meeting in Salt Lake City in 1926 principally to hear a paper being presented by Doctor Sorensen on vacuum switches. Later, when Doctor Sorensen brought some of these switches to Schenectady to be tested in the switchgear short-circuit testing station, Prince was selected to assist. This was his first intimate contact with switchgear, and between tests on the vacuum switches, he inspected and asked lots of questions about the oil circuit breakers which he saw around the station. This interest continued and in 1929 he was appointed research engineer of the switchgear department.

Prince came to the switchgear organization with a complete lack of knowledge of the things which could not be done. Circuit breakers had been improved continuously over the period of the previous ten years. They had not reached a state of perfection, but generally were conceded to be highly developed. It was the general impression of those connected with this business, for instance, that it was folly to think of building a high voltage oil circuit breaker with less than one-tenth of the amount of oil contained in conventional breakers, or one which would interrupt a short circuit in one-sixth of the time of the good breakers of that day, or one in which porcelain would replace good heavy thick steel. Prince did not share in this impression, but proceeded to develop such a breaker and to design many other important, but possibly less spectacular, things. He did them because he had the imagination and courage to think and plan for progress not by small increments, but by bold, broad steps.

Lamme Medalists

1928	Allan Bertram Field	1937	Robert E. Doherty
1929	Rudolf E. Hellmund	1938	Marion A. Savage
1930	William J. Foster	1939	Norman W. Storer
1931	Guiseppe Faccioli	1940	Comfort A. Adams
1932	Edward Weston	1941	Forrest E. Ricketts
1933	Lewis B. Stillwell	1942	Joseph Slepian
1934	Henry E. Warren	1943	A. H. Kehoe
1935	Vannevar Bush	1944	S. H. Mortensen
1936	Frank Conrad	1945	David C. Prince

Not all of the ideas which he developed so successfully were original with him. One of his first moves after joining the switchgear department was to study the patent file. There he uncovered a patent on the oil-blast arc-control device in the interrupting structure of oil circuit breakers which had been left dormant for a number of years. He continued the development of this principle, and brought it to a successful conclusion so that it was of major importance not only in new lines of circuit breakers then being built, but possibly more important, in its successful application to many breakers already in the field to provide them with the benefits of modern performance and to ward off obsolescence.

His major achievement in this field was the development of the entirely new low-oil-content impulse-type circuit breaker for the 287,000-volt Boulder Dam line. Up to that time, breakers had been built which would operate in eight cycles, but the requirements for this transmission line demanded 3-cycle operation, and at a higher voltage than any breakers ever built. Two of the stations requiring these breakers were in isolated locations in the desert where oil handling facilities would be dictated solely by the requirements for the circuit breakers, there being no other apparatus using oil. Prince had done some work with lower voltage breakers employing a mechanically operated piston to force oil across a pair of contacts to bring about prompt and consistent operation at 11,000 volts. This principle was adapted easily to a mechanical arrangement which used only a fraction of the oil found in conventional large tank-type circuit breakers. The oil was used for interruption only and not for insulation to ground. He reasoned that if he could put enough of these breaks in series, and could get them to share the duty, the principle could be extended to the higher voltages.

His first crude sample, using eight breaks across which oil was forced by the action of a single piston, was made from pipe fittings and other odd bits and pieces readily available. It looked like nothing that ever had been seen before in the circuit breaker field, but it worked. Many of the multitude of mechanical design problems incident to translating the principle embodied in this first sample into a finished product were solved by characteristic bold departure from customary practice. The success of this venture, which might be considered symbolic of the principle of breaking with tradition, may be judged best by the fact that the first circuit breakers of this type have completed ten years of successful service. More were placed in service later for these same lines, while others for lower voltages have found application

in other parts of the United States and Europe when their particular features appeared best adapted for a specific application.

It is particularly significant to note evidence that Prince's spirit of invention is contagious. While he was busy bringing forth ideas about many other types of circuit breakers and accessories, which there is not space to chronicle here, he was successful in inspiring others to do likewise. The number of new ideas submitted to the patent department of the General Electric Company from the switchgear engineers showed an appreciable upward trend after Prince joined the organization.

In 1940 Prince was brought back to Schenectady and named manager of commercial engineering for the apparatus department. Eighteen months later he was elected vice-president. In this executive capacity he still finds outlet for his inventive ability. For many years he has been a student of economics although he modestly insists that Mrs. Prince is responsible for inspiring most of his activity. In developing some of his ideas along this line, he prevailed upon Charles E. Wilson to speak at the 1941 AIEE winter convention, Philadelphia, Pa., on "The Challenge to Private Enterprise" (*Electrical Engineering*, March 1941, pages 99–104).

Later, while the National Defense Program and the War Projects Committee, of which he was a member, were taking most of his time, he was named chairman of a special planning committee in the company. This group was organized to formulate general plans for the postwar reconversion in order to save time in the reemployment and the return to peacetime production. At the same time, Prince was a member of the National Committee for Economic Development.

As president of the AIEE (1941–42), he visited many Sections, inspiring engineers to think ahead, not only in terms of the future of their specific assignments, but also in broad terms of the help which they might be as a group in the national postwar economy. In recognition of this activity, Prince was awarded an honorary degree of doctor of science in 1943 by Union College.

Early in 1945 Prince was placed in charge of the combined general engineering and consulting laboratories which serve the whole company. In this capacity, he finds an outlet for his skill and aggressiveness in the development field, and is engaged in many activities which he sincerely believes will make the world of tomorrow a better place in which to live.

Prince is firmly convinced, and in practice has carried out the idea, that a real inventer can find himself at home in any field. He maintains that inventive and thinking engineers can have an important voice in shaping the economic and political future of the United States as well as in its progress in material things.

The Lamme Medal committee truly was inspired in selecting David C. Prince as the recipient of the medal on which is engraved—"The engineer views hopefully the hitherto unattainable."

The Lamme Medal Inscription

DAVID C. PRINCE
FELLOW AIEE

The engineer's hopeful attitude toward the hitherto unattainable has been justified by his accomplishment, time and again, of the seemingly impossible. Inasmuch as he is able to achieve such gratifying results in his own field, perhaps his methods could be applied with equal success in the wider field of human relations.

"THE engineer views hopefully the hitherto unattainable." The inscription on the Lamme Medal long has been an inspiration to me as I am sure it has been to a great many other engineers.

The engineer grasps at the seemingly unattainable, fails, and optimistically tries again, and the records prove

David C. Prince is vice-president in charge of application engineering, apparatus department, General Electric Company, Schenectady, N. Y.

Essential substance of an address delivered during the Lamme Medal presentation ceremony at the AIEE summer convention, Detroit, Mich., June 24–28, 1946.

Figure 1. 220-kv oil-blast circuit breaker constructed from pipe fittings

Figure 2. Boulder Dam circuit breaker, successor to circuit breaker shown in Figure 1

Figure 3. Polyphase directional relays (General Electric)

Right-side oblique front view showing comparative size. Left, 1931; middle, 1932; right, 1937

that he is justified fully in doing so for he has gone on to achieve, time after time, what once was thought impossible. In my own experience, for instance, a lot of things have been accomplished which, at one time, were just vague hopes that many people did not share. As an example, Figure 1 shows a collection of pipe fittings, the first sample of the circuit breakers which later were built for Boulder Dam. At the time the equipment was assembled anyone who regarded it as a circuit breaker was not taken very seriously. However, when you think in terms of fundamentals, you realize that, after all, a switch really does not do any work. It merely carries currents when it is closed, in which capacity it is about as effective as a straight piece of copper wire, and it prevents the flow of current when it is open, at which point it is doing approximately the job of a good insulator. Thus, the ideal circuit breaker simply should be an insulator with some means of rendering it conducting or nonconducting and that, if you discount the traditional view, is exactly what the pipe fitting collection was.

Figure 2 shows what this circuit breaker eventually became. (It later was moved out into the desert between Boulder Dam and Los Angeles, Calif.) This idea, of course, is only one example of the engineer's hopeful attitude toward progress. This type of progress is not limited at all to those devices which really have no work to do, but is characteristic of many lines of activity.

THE RELAY

Advance in another field, relays, is illustrated in Figure 3. In 1921 we started with a large relay which was both slow and inaccurate. We then reduced the size. We attained the "unattainable" in 1932, and took still another cut out of it in 1937, so we know on the basis of past experience, that, having attained the unattainable in any given year, we may expect with equal hopefulness to attain it again, even in the same line, six years later.

A new gain often is made possible by other previous gains, such as in the case of metalclad switchgear (Figure 4), and each one of these gains was made possible by other gains that occurred in some auxiliary apparatus. Thus, as the snowball rolls, each time we discover something new and attain some new "unattainable" thing, each discovery gives us new vision so that we can view other unattainable heights with hope for realization in the future. These discoveries are not limited, of course, to switchgear either. From 1930 to 1934 the volume of one line of static capacitors was reduced in three stages to approximately 25 per cent of the volume at the beginning

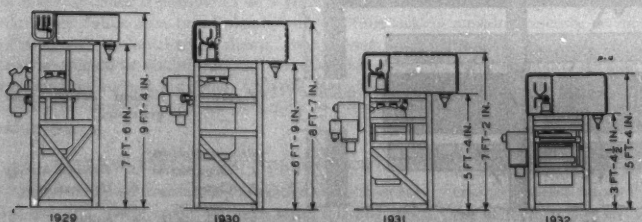

Figure 4. Progressive development of indoor metalclad switchgear

of the period. Power transformers have shrunk nearly 50 per cent in size and weight.

ADVANCE IN OTHER FIELDS

Nor are these advances limited to apparatus like transformers and capacitors which deal only with electricity. The motor, standby for making the conversion from electricity to mechanical power, also shows a record of continuous advancement. (Figure 5.) Not only has this progress been made year after year in one of the oldest of electrical tools, but the advances continue nearly unabated without any sign of tapering off. Here we have the record, the proof of why the engineer now, just as in Lamme's time, can view the hitherto unattainable hopefully. The automotive people have made continuous progress in automotive vehicles; the airplane people have made continuous progress; the chemical engineers have made continuous progress in their medium; and the electrical engineer is accelerating the rate of that progress.

The process of evolution is not limited to the engineering profession. The medical profession certainly has accomplished outstanding improvements in its activities thus far, and there is no reason why anybody should expect a lack of progress or an end to the continuous improvement of conditions.

UNIVERSAL PROBLEMS

Under such circumstances, why is it that there are so many people who are without hope; who are in despair at the present time? They look about them despairingly, they see the chaotic conditions of the world and everything looks black. They seem to feel that optimism may be justified in engineering matters but, for the world at large, hope must be abandoned. They particularly feel this despair in the face of demands for full employment and a high standard of living, and in the all-important desire for world peace. They feel that we are helpless; that mechanical tools and technical

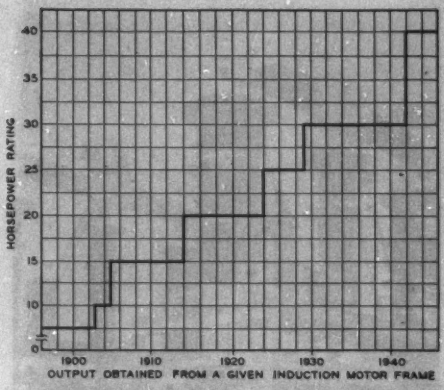

Figure 5. Output obtained from a given induction motor frame

tools abandon us to our fate when we approach those subjects which are not regarded as definitely within the field of the engineer.

That is not necessarily true. There is no reason why the engineer should be helpless in the face of these more universal problems. Perhaps we should analyze the situation a little and see what the characteristics of the unattainable are, this unattainable that is viewed hopefully by the engineer. A rather definite line goes through engineering science which many people have overlooked and that is the line which depends on whether we are viewing the science as an operational matter or observational matter. When an astronomer views the stars, he knows perfectly well that any kind of observation he may make will not alter in any manner the progress of the stars or their movements. The same applies to a man who is going to view a minute electric

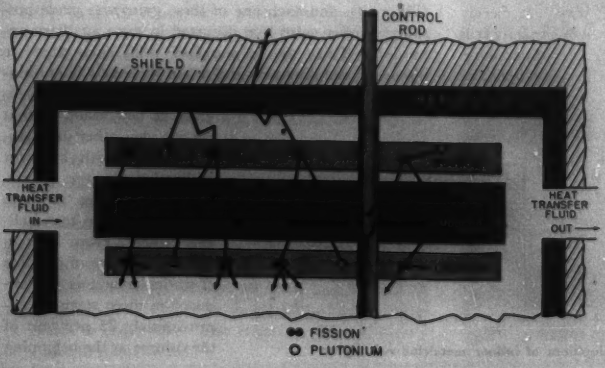

Figure 6. Nuclear energy heat generator

Research problems:

1. *Chain reaction*
2. *Control*
3. *Plutonium*
4. *Poison effects*
5. *Radiation stability*
6. *Heat transfer*
7. *Corrosion*
8. *Shielding*
9. *Size*

current. If he does his work well, he must measure that electric current so that nothing which he does will alter the amount of that electric current, otherwise he has failed in his scientific job of accurate observation, and, as long as we think of science in terms of accurate observation, the ideal is not to make things better, but to repeat the truth with the absolute maximum of accuracy. I think, in general, we will find, when we get into those fields where little progress has been made, that the approach has been an observational approach. The objective has been a search for truth, not the attainment of the hitherto unattainable.

If this is a true estimate of the situation, then what must be done is for the engineer to move over into those fields whose heights have been monopolized by the observational scientists and to bring to bear the operational point of view as represented by these cases where the impossible has been approached and realized, at least partially, again and again.

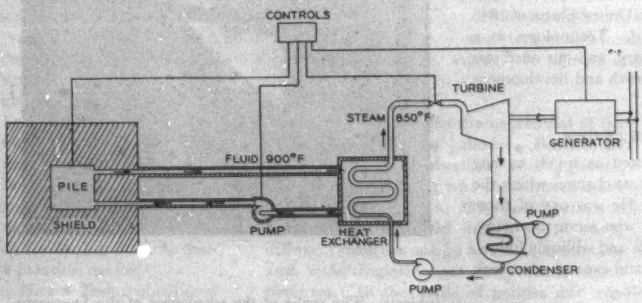

Figure 7. Diagram of fluid convection transfer systems

With particular respect to economic matters and the desire for high levels of production and employment, there are certain technical things which were developed during the war that the engineer can offer and which will be of immeasurable help in that area of endeavor. For example, the development of mechanical machines which perform mathematical operations with great speed and in that way make it possible to do a great many things that could not be done before simply because of the lack of time and personnel to do them. By applying these tools we should be able to measure the operation of our economy in such a way that we shall know at once what is happening in time for something practical to be done about it.

NUCLEAR ENERGY AND WORLD PEACE

When we go on to consider the matter of world peace we find that there again we have some startling new engineering tools coming to our aid.

Figure 6 shows, in diagrammatic form, what a nuclear pile is like.

A pile is the instrument or apparatus that is used to develop power from nuclear energy. In the chain-reacting pile uranium may be used as the active agent with a moderator that slows the neutrons down, and the fissionable material, plutonium, is produced. In the the operation of fissions, of either the uranium or plutonium, heat is produced which may be utilized for the development of power.

Figure 7 illustrates diagrammatically how the power may be obtained and employed. It is necessary to have a circulating medium going into the fission unit shown in partial diagram in Figure 6, because there are great volumes of radiation which are rather unhealthy for anyone in proximity. We then get heat from heat transfer units and produce steam which can operate any standard turbine either for the use of an electric generating plant or directly, as in the diagram, to give the propellers of a ship the necessary power.

What might one expect to accomplish by such a device? A modern destroyer driven by nuclear power could go a million miles at 35 knots on just 15 tons of fuel. That is just one indication of the tremendous developments possible and it should show anyone beyond a doubt that isolationism no longer exists in this world. It just is not possible any more and so we must view hopefully, if we are to do it at all, a future in which we are going to be dealing with far larger powers than ever have been available to man before.

I am not able to say, of course, even if I knew, how this powerful new tool that is being handed over to the engineers is going to be used to bring about world peace, but it is evident that those who understand how a tool of this type works are going to play a necessary part in deciding how it will be employed and in making the American people realize what it means to have this amazing resource at our disposal. At the present we probably can do nothing more valuable than support the Baruch Report, because there is no question but that international control of atomic energy is necessary if it is to be the power for good that we all want to make it rather than have it, like Frankenstein's monster, destroy those who conceived it. So we turn back then to Mr. Lamme and his simple expression of opinion, "The engineer views hopefully the hitherto unattainable." All of these things are attainable to the engineer who views the future hopefully and does something about it.

George Westinghouse—Individualist

J. K. B. HARE

GEORGE WESTINGHOUSE was born in 1846—exactly 100 years ago. At that time, the United States west of the Mississippi was largely Indian territory; or Oregon country disputed between the United States and Great Britain; or what is now California, but was then a part of Mexico—a nation with which the United States was about to engage in war over the annexation of Texas. James Polk was in the White House; and emigrations were under way to California and Oregon, with the Mormons moving West.

Technological progress was stirring, though feebly. The first telegraph line was in service between Baltimore and Washington, and the Pennsylvania Railroad just was being established. Life in the United States of 1846 was rugged, and living was hard. Technology, as a word, did not exist in the dictionary, and our ancestors were not concerned about the growth and development of large corporations.

WESTINGHOUSE; THE LEADER

George Westinghouse contributed as much as any man in the past 100 years to the vast changes which the United States has encountered. He was one of those few creative geniuses of all time who serve the many, one of those on whom the rest lean and willingly follow. As followers, we only can perfect and expand what men of his caliber conceive and originate.

There was no mistaking the character of George Westinghouse. As a small boy, I grew up within a few blocks of his home. I saw him daily, and he looked the part of and spoke as a leader.

George Westinghouse was granted his first patent in 1865, when he was 19 years old (the year the Civil War ended) and he died 49 years later. His active engineering and business life thus was spent during two major wars; during a period of rapid industrial progress, when the spirit of the times and the thinking of the people were favorable to the development of giants.

In this anniversary year American industry acknowledges the engineering and industrial achievements of one of its giants, and so I wish to remind the reader of his contributions to the development and growth of the electrical arts. However, I also wish to pay tribute to the man, George Westinghouse, pioneer and individualist, and to point out the changes in spirit that have occurred within the generation that has grown up in the 32 years since his death.

Very recently, the city of Pittsburgh went through an experience which focused sharp attention on both of these subjects. The strike of the employees of the Duquesne Light Company stopped the transportation system, shut down industries not already idle because of the steel and electrical industry strikes, vacated schools and theaters, and killed practically all of the varied activities of a modern city, except those absolutely essential to health, public safety, and life itself.

The strike was only one evidence of the deep changes in social, labor, political, and industrial thinking that have occurred since George Westinghouse's death. The vital importance of the electrical industry to daily life was brought home to Pittsburghers with real suddenness and stark reality. Householders realized, possibly for the first time, that, in addition to its obvious uses for light, cooking, and domestic tasks, electricity was required to keep home-heating furnaces in operation; to keep food from spoiling in homes and stores; to process the daily milk supply; and to bring news into the home by newspaper and radio.

Essential substance of a paper presented at the AIEE summer convention, Detroit, Mich., June 24–28, 1946.

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INDUSTRIAL CONTRIBUTIONS

The electrical industry, which was truly an infant when George Westinghouse first became interested 60 years ago, has grown into an indispensable part of the daily living of every person. It is a valued servant, but, together with other features of modern living, it has made us absolutely dependent upon reasonable co-operation and a decent regard for the rights of each other, and of the public, in our social organization.

In the railroad field, George Westinghouse made his contributions in the air brake, draft gear, and railway signaling. In the electrical field, he made his contribution indirectly through the engineering and commercial development of other men's inventions. His was the imagination, the energy, the ability to see the value in other men's ideas, to make them useful in forms of steel and copper, and to promote and sell them to an amazed and sometimes bewildered public.

Undoubtedly the greatest contribution of George Westinghouse to the electrical industry was his development and active promotion of the a-c polyphase system.

Although he made mechanical contributions of his own, the polyphase system was the work of many inventers. The French engineer, Gaulard, and the Englishman, Gibbs, contributed the basic transformer; but Westinghouse (aided by William Stanley and Albert Schmid) redesigned the crude invention of Gaulard and Gibbs into a practical device.

Nicola Tesla contributed to the induction motor principle while Oliver Shallenberger used the same rotating field principle in his watt-hour meter.

It only adds to the stature of George Westinghouse that he could imagine the possibilities of these components as a complete power system, and could bring together men of such varied talents and characteristics in a co-operative team; that he could organize and staff his companies, and thereby multiply his own great talent and power. His courage and resourcefulness were demonstrated in overcoming the technical problems and the somewhat hysterical public opposition to the supposedly greater hazards to life of high voltage alternating current.

He boldly accepted the contract to supply electric light and power for the Columbian Exposition, or World's Fair, at Chicago, Ill., before he had available a successful, noninfringing electric lamp, and when the Tesla induction motor barely had been born.

Soon after the successful opening of the Chicago World's Fair, George Westinghouse and his electrical manufacturing company undertook the construction of the 5,000-horsepower polyphase alternators for Niagara Falls. It is difficult for us, after 50 years of development, to appreciate the electrical and mechanical engineering problems involved; not only for the main generators, but for the circuit breakers, measuring and operating instruments necessary for the operation of a practical system.

George Westinghouse was responsible for bringing the Parsons steam turbine to the United States from England. Francis Hodgkinson and B. G. Lamme, Westinghouse engineers, were leaders in the development of the modern turbine generator unit. George Westinghouse acquired the McAlpin-Melville marine gear patents, and he was a pioneer in the application of economical high-speed turbines to ship propulsion. Again, through the work of Lamme and other Westinghouse engineers, his companies introduced the a-c railway system to this country.

There were giants in those days! And the climate and conditions were favorable for their growth and development. A railroad still was considered a community asset, and corporation officers were held to be respectable!

This year, 1946, marks the centennial of the birth of George Westinghouse. Born in an era of "rugged individualism," Westinghouse, himself, was a pioneer who contributed much to industrial advances. If he could return to earth today he would find a world vastly different from the one he knew. Scientifically and technologically, we have made much progress. In the fields of politics and economics, also, society has come a long way from the individualistic era of George Westinghouse, but it is highly debatable as to whether or not it has been in the right direction.

THE NEW GENERATION

What has happened to the United States during the generation since the death of George Westinghouse? What have we done with the heritage he and his contemporaries left us? If he could return to the scene of his work, and if his spirit could communicate his impressions to us, what would he say of our times and our work?

On the scientific and engineering side, he would find much to interest him, and I think he would be highly pleased. I imagine he would get busy immediately on the organization of a Westinghouse Atomic Power Corporation! He would be puzzled possibly, however, by the fact that the United States Government would not permit him to do any such thing.

In the social and economic fields, he would be pleased with high earned-wage rates and the vast improvement in factory working conditions. But he also would find much that would puzzle, if not amaze, him—much that he simply would not understand. And it is questionable whether we ourselves understand the problems with which we are confronted, because in our complex society, with its division of labor and its free exchange

of the products of labor, there are certain fundamentals without which our society cannot function.

Let us say it this way: There is a minimum of individual responsibility, a minimum of good will, a minimum quality of leadership below which we cannot go and still preserve a functioning society under complicated modern conditions. We have fallen, during the past few months, dangerously close to that minimum, if we actually have not gone below it.

Let us look at these three essentials: individual responsibility, good will, and leadership. What has happened to them since George Westinghouse lived among us some 30 years ago? And, more particularly, what has happened to them during the past dozen years?

INDIVIDUAL RESPONSIBILITY

Individual responsibility, resourcefulness, initiative, have been undermined by years of propaganda supporting government responsibility for jobs; for maintaining purchasing power; for increasing farm prices; for "holding the line" for all other prices; and for a Utopia of employment and permanent prosperity. I use the word "Utopia" advisedly, because every scheme for a planned society, from Plato's "Republic" to the Soviet Union, has required some form of dictatorship to run it.

During these years, Americans have moved a long way from the individualism of George Westinghouse, from faith and confidence of individuals in private enterprise, toward the planned economy of all-powerful government controls and subordination of purchasing power. I believe that Westinghouse was interested only in increasing earning power; and there is a vast difference between these two. It does not matter seriously how much we earn, if we earn it. There cannot be a sound economy in a state which tries to increase earning power by increasing purchasing power, as such. In other words, purchasing power that comes from earning power is always good; purchasing power that comes from any other source is suspect, and usually fails in its purpose.

To equalize earning power in the community, in the nation, throughout the world, is good because maximum trade will exist when all men are uniformly good customers, because of uniformly high earning power.

But equalizing purchasing power, except through individual earning power, is a Socialist delusion as many old and current experiments have demonstrated.

George Westinghouse, I am sure, believed in increasing and equalizing earning power. I am equally sure he would be bewildered and annoyed if one of the modern disciples of government-spending would maintain his purchasing power for him otherwise.

GOOD WILL

Good will between industrial leaders and employees, good will between business men and the public, has been destroyed systematically by government and by labor union propaganda.

Workers have been told that there are "hidden profits" and unnecessary reserves in "big business"; government agencies have circulated "confidential" reports (some later repudiated) to the effect that industry generally could pay higher wages if it "would put human values ahead of profits."

The people have been taught that profits are a social evil, that in some way, never explained, everyone could enjoy a life of abundance if only industry were not strangled by the profit motive.

It should not be necessary to explain that savings out of profits enable industry to increase its productivity and thereby increase real wages.

Strange as it may seem to radical reformers, liberal profits make higher wages possible. Real wages over the past 40 years, and, in fact, for centuries past, have increased almost directly with the investment per worker and the mechanical power available per worker.

The most capable and the most successful American corporations have been pilloried because of their success. The people have been taught, too effectively and dangerously, that industry in general is oppressive, is dishonest, and is the enemy of the common people. These words are strong, but they are not put too strongly to convey the fact that the labor-management problem today is one that requires the highest type of leadership in order to cement some measure of good will between these two essential factors, in the success of our economy, and in fact, of the United States as a nation.

LEADERSHIP

The third essential of a continuing society based on the division and specialization of labor, and the free exchange of goods, is the absolute necessity for at least a minimum quality of leadership at this time.

George Westinghouse and his contemporaries looked to leaders to guide material economy and he naturally and inevitably assumed his own large share of this responsibility. It has been popular since the "great depression" to belittle the quality and success of business leadership. This is one of the calculated results of the campaign of villification that has been pursued for a dozen years.

But, over the longer view, American business leadership has no reason to apologize for its record. Under this leadership, the United States has become, in spite of human shortcomings and failures, the most desirable place in this troubled world in which to live. During the past 12 years, this leadership of industry, and for our material well-being, gradually has shifted to Washington, D. C., and to the leaders of organized labor. After the experience of recent months, are we satisfied with the accomplishments of this new leadership?

One important factor which the leaders of our present economy have overlooked lies in the fact that industrial

leaders, at their very worst (and there have been some who were not too good) of self-seeking and abuse of power (and there were some abuses of power, as is well known), were producing and developing the United States; and, at the same time, they were increasing jobs and increasing income. They could advance their own interests mostly by increasing production, and so they could not help being on the side of production.

But political leaders, and labor leaders, at their best can hardly help industry to produce. They do not contribute directly to the production of wealth; their major purpose is to redistribute wealth. At their worst, and we have seen some of it during the past few months, political and labor leaders get in the way of production, and jobs, and better living.

George Westinghouse lived his active life, and did his work, in a world that took private enterprise for granted. His times were still close enough to the European planned economies of the 18th century from which Americans escaped, by the determination and wisdom of the fathers of the republic of the United States. These fathers, and the generation of Westinghouse, knew and feared the all-powerful government that planned economy requires. They valued the individual freedom that must be paid for by individual responsibility, sometimes by dangerous insecurity.

George Westinghouse, for one, was no timid advocate of security, and paid the full penalty for the lack of it in the year 1907. At that time, painting with a wide brush and with a boldness which was one of his characteristics, he found himself overextended and lacking the necessary funds with which to carry on those many ventures which he had conceived and which were then in the mill. Bankers were necessary; and it is to be noted that they did a constructive job in assisting the Westinghouse Electric Company again to walk alone.

It was not the first time that Westinghouse had been out of money; but the aftermath of this meant his physical separation from the company which he had founded, and to which he had contributed so much.

If George Westinghouse could communicate with us today, I am sure he would tell us that the real reactionaries are those who would have us go back to the government-planned economy and the state-monopolies of a century and a half ago. He would tell us that peacetime growth and progress come most fruitfully from individual liberty, from the release of individual genius such as he himself displayed.

One of the major fallacies of state-planned economy is that growth can be planned. The development of an idea, an invention, an industry, is unpredictable. Growth, or stagnation, is in the hands of our leaders!

George Westinghouse—engineer, organizer, pioneer, individualist, great American—surely would approve of that fact if he were alive today.

The Engineer and the Union

HOWARD D. BURNS
STUDENT MEMBER AIEE

COLLECTIVE BARGAINING, as carried on by labor unions with employers, has two principal aspects. In the first place, it is a method of price-making—making the price of labor. In the second place, it is a method of introducing civil rights into industry, that is, of requiring that management be conducted by rule rather than by arbitrary decision. In this latter aspect, collective bargaining becomes a method of building up a system of "industrial jurisprudence."

Wage earners have many specific purposes in seeking to build up a system of industrial jurisprudence. They wish to protect their organizations against being weakened by employers who might discriminate against union members; to strengthen their organizations by making union membership an aid to employment; to allocate limited opportunities to work; to make more

Essential substance of a paper presented at the Student Branch conference held during the AIEE Southern District meeting, Asheville, N. C., May 14-16, 1946.

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The author wishes to express his appreciation to O. W. Eshbach, dean, Northwestern University, Evanston, Ill., and vice-chairman of the AIEE committee on collective bargaining and related matters, for making available a selection of articles from his personal files as well as the AIEE report of the committee.

work for themselves; to protect themselves against the cost and impact of technological change.

UNION POLICIES

The system of industrial rights and duties which collective bargaining endeavors to establish deals with such matters as entrance to the trade, hiring, training, promotion, reduction of staff, technological change, and methods of compensation. The specific policies pursued by different unions and the rules which they seek to enforce differ greatly. The introduction of technological change into industry produces various policies. Some unions oppose technological changes; others seek to compete with new methods and new processes by making concessions on old methods; still others seek to control the introduction of new machinery and methods. Frequently, a combination of these several policies is pursued simultaneously. Various unions differ on policies regarding piecework or bonus systems. To some extent these variations in union policies and union rules are simply the result of differences in experience or differences in the intelligence and foresight of union leadership.

In a period of increasingly strong labor unions the engineer finds himself on the proverbial horns of a dilemma; whether or not, as a member of a profession, he would be benefitted by unionization. Because of the vital importance of such a decision to the many young men just entering the engineering field, and to the profession, *Electrical Engineering* presents the viewpoint of one of their number, a Student Member of the AIEE.

In human society, "labor" is no more a problem than are our professional groups of engineers and physicians. Labor cannot be solved like a problem in geometry. Labor and engineering are each continuing relationships, with changing emphasis—not problems which can be solved and then put out of the mind.

Of the many statements defining labor, capital, and organization of engineering, none ever has been so clear and vivid as the truism generally credited to Andrew Carnegie, "Industry is a three-legged stool, whose legs are capital, business (organization or management), and labor." Certainly only when these legs are kept of the same general length is the stool comfortable.

Unions continually must obtain increasing benefits for their members, else they fail. What labor and the public do not understand, however, is that the steady wage increases that have occurred in the past 50 years would have been utterly impossible had it not been for the efforts of the technologists.

Technical economy, which really made possible the increased wages of the union worker, now is unable to keep up its end of the race. The profit is being taken out of capital, and if labor is to demand an ever-increasing wage rate, technology and management cannot provide the wherewithal—and bankruptcy must follow. Then, if the industry is essential, either the state or the worker must take over industry and run it.

The more union labor freezes wages at an irreducible level, the slower the reabsorption of labor following an intensive invention, and the more difficult the engineering and management part of the problem.

It seems that engineers stand somewhere between capital and labor, but always with an opportunity to move up into the capital and executive bracket. If engineers unionize, will they still have the opportunity of advancing into this upper bracket? There are numerous arguments for and against the unionization of engineers. An attempt will be made in this article to discuss both sides of the question.

ENGINEER'S STATUS

Engineers attain professional status in a unique way. Upon completion of the prescribed formal education for their prospective fields, lawyers and physicians are inducted immediately into the profession by joining forces with others of the same profession in an established office or by opening an office of their own. This is not usually true in the case of the engineer. An engineer, upon the completion of his formal education, may obtain employment as general roustabout doing things which more often than not give no immediate evidence of a need of higher mathematics, advanced engineering knowledge, or ability to apply engineering technique. This means that the young engineer, coming out of school, must gain his practical experience and earn his professional status in the rough and tumble of the subprofessional group, only partly protected by his technical standing.

In this stage of his career he is, in all probability, an employee, and as such he can avail himself of the protection afforded by the legislation which greatly promotes collective bargaining; for example, the National Labor Relations Act of 1935.

Section 8 of the Wagner Act specifically states that it shall be an unfair labor practice for an employer:

1. "To interfere with, restrain, or coerce employees in the exercise of the rights guaranteed in Section 7" which reads "employees shall have the right to self-organization, to form, join or assist labor organizations, to bargain collectively through representatives of their own choosing, and to engage in concerted activities, for the purpose of collective bargaining or other mutual aid or protection."

2. "To dominate or interfere with the formation or administration of any labor organization or contribute financial or other support to it . . . ."

This was followed three years later by the Wage-Hour Law, which fixed a minimum rate of pay of 40 cents an hour and a maximum work week of 40 hours, and

imposed new restrictions on employers with penalties for their violation.

The law, however, does not compel professional employees to join a labor union, unless a majority of a group of such employees votes in favor of joining.

"In general, technical employees . . . are paid on a salary basis and have much different qualifications than the production employees; a substantial number of technical employees are college graduates. In accordance with our customary policy, we shall exclude technical employees from the appropriate unit."
(Sunbeam Electric Manufacturing Company, 42 NLRB 825, July 23, 1942.)

"We believe that the desire of these employees themselves is the chief factor to be considered in determining whether they shall constitute a separate unit or become part of a larger unit."
(Simmonds Aerocessories, Inc., 42 NLRB 179, July 8, 1942.)

"We hold, therefore, that the desires of the employees shall govern, and we shall direct that separate elections be held."
(American Smelting and Refining Company, 42 NLRB 736, July 22, 1942.)

These decisions make it clear that the National Labor Relations Board will not force technical employees against their will into a union of production employees, but they also show that if a majority of a group of technical employees wishes an organization for collective bargaining, the board will approve it.

The engineer has the choice of working his way up with what help his profession can give him (if necessary, in cases of unfair discrimination, he can avail himself of recent legislation and form with others a bargaining group unaffiliated with organized labor); or he can join with organized labor. If he chooses the latter course, he becomes a member of the labor group and relinquishes his rightful place as a part of management. If he joins with organized labor he contributes financially to the support of the labor pressure group, which certainly is not looking out for the interest of the profession or of management.

STRENGTH OF LABOR UNIONS

In 1929, one of the most prosperous peacetime years, the membership of organized labor totalled approximately 3.5 million workers. During the depression, labor union membership declined to less than 3 million. In 1933 the labor movement surged forward aided by improved business conditions. Today labor organizations, according to various estimates, have a membership of between 12 and 13 million, and wage contracts negotiated by them probably apply to an additional three or four million.

Because of the trend of the times and recent legislation, labor unions have grown strong as a matter of course and have obtained for their members remuneration out of proportion to that of other types of employees, such as those in the engineering profession. Because of the fact that so many engineers are employees needing group strength, they look sympathetically on this trend toward grouping, collective bargaining, and unions.

One of the most frequent arguments against the unionization of engineers is the claim that unions tend to increase the costs of production, while it is the business of the engineer to reduce the same. This claim may refer to various points. The first one is the question of wages, the primary objective of union activities. The wage question is not an engineering problem, it is a matter of bargaining and of supply and demand on the labor market. The second point is a better utilization of labor by means of motion studies, improved organization, better tools and machines, and the other well-known methods. These are engineering problems, but they, too, interfere with the spreading of employment, consequently, even the most gifted, experienced, and zealous engineer will not be able to overcome the reluctance of the workers against these methods, whether he be union member himself or not.

Whatever the truth of the matter, the question in the present connection is whether the engineer could secure a smoother flow of operation and co-operation from the employees under him, if he, too, were a union member.

At present, the unionized worker, even though he may have a personal esteem toward some individual engineer, looks with contempt and scorn at the non-unionized engineer in general whom he considers to be an employee like himself, even if of a different trade, only with not enough backbone and intelligence to join a union. Many believe that this unsound relationship between engineer and worker could be changed for a much better one if the former, too, would become a union member. There is a probability that some of the present labor troubles might have been avoided through the more reasonable, cool-blooded, and intelligent active co-operation of union-member engineers.

Viewing the situation from another angle, union membership tends to draw a line between employers, who are defined as persons with the right to hire and fire, and employees. In the case of engineers this would mean in many instances that the older more experienced men, from whom the younger men should learn, could not belong to the same organization as the younger engineer.

The typical union is concerned exclusively with the economic well-being of its members, and with the public welfare only insofar as the union members may be able to take advantage of that welfare. Is this a suitable and proper attitude for a profession?

"A profession is a calling dealing with spiritual, physical, or social laws, principles and aspirations, and requiring expert knowledge, inherent skill, and strong moral purpose in the application of the same to the conduct of life and the affairs of men."

ENGINEERING IDEALS

The highest ideals of the engineering profession were expressed forcefully by Doctor Vannevar Bush in his address before the meeting of the American Engineering Council in January 1939. He spoke of "the heights of

true professional attainment, where honor and individual recognition by fellows is the real reward, and where the watchword is that old, old theme, which has never lost its power, and which yet may save a sorry world, simple ministration to the people."

Engineers in a number of occupations and localities have been subjected to considerable pressure to unionize. This pressure usually is brought about by outside organizations, rather than from the engineers themselves. Most of the engineers who have urged unionization are those engineering graduates who never really have become engineers because of inability to keep up with the advancements of the profession; or who have been so unfortunate as to obtain employment with firms having the short-sighted policy of getting from their technical staffs all the service possible by paying a minimum wage rather than a just compensation for the work done.

Mr. Average Engineer has overwhelming power technically, but as a professional unit his voice has been inaudible. He is a member of the youngest of all the learned professions, in which most of the branches are not yet a lifetime old. In a day of economic confusion when great new forces are sweeping over us in industry, he cannot, if he would, remain a solo performer.

Thus engineers in industry are faced with a question which, for any particular group, may at any moment become acute and pressing. Should they set up a collective bargaining agency of their own to serve their own interests and forestall a possible attempted grab by a production union?

If collective bargaining is desirable for engineers, then the answer seems clear. An agency organized by the engineers themselves obviously would be equipped better for such purpose, in understanding and common interest, than a union of production employees.

ROLE OF THE ENGINEERING SOCIETIES

The question as to whether engineers shall or shall not become members of a union must be considered entirely as a personal matter for each individual, who as such has the free right to choose what seems the better way.

One answer is a more active interest by the already established and respected national engineering societies in the various conditions of employment of engineers; in the education of their members in the legal and economic elements of collective bargaining; in giving to young engineers and those in the subprofessional group the special consideration they need; and in providing advice and help where there are acute employment difficulties.

The basic purpose of the American Association of Engineers, the National Society of Professional Engineers, and such organizations as the Bar Association and American Medical Association is similar to that of unions—that of advancing the economic position of the membership through collective action. But they differ radically in methods and in the fact that they include in their membership both employers and employees.

Let us not be deceived, the labor idea is widespread and growing among many young engineering graduates. If older engineers somehow do not make our great mass of younger graduates professionally minded, within a few years we may be largely trade union in pattern.

Actually, very few professional engineers have joined labor unions. Nevertheless, the difference between the remuneration of the profession and that of labor is unfair and some employee engineers definitely are seeking aid. One thing is clear—some engineers need help and this help should come from the profession itself.

In the writer's opinion, engineers and labor unions have so little in common that unionization of engineers is at least an unnatural development.

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The Automatic Sequence Controlled Calculator—II

HOWARD H. AIKEN GRACE M. HOPPER

THE REGISTERS GIVEN over to multiplication, division, and the functional units are shown in Figure 1. The counter wheels and allied controls involved in these two operations are interconnected electrically, in such a way that both multiplication and division cannot be carried on at the same time. The basic mode of operation is shown in the schematic diagram, Figure 2. In the case of multiplication, the multiplicand and the multiplier are read into the unit through in-relays connected to the bus as in the case of the storage counters. The out-relay, however, through which the product is read out of the multiply unit, connects to the bus through a plugboard provided to fix the decimal point relationship between the product counter and the bus.

The location of the decimal point is of no importance as far as the operation of the storage counters is concerned. When the operating decimal point is assumed to lie between columns n and $n+1$ in the switches and storage counters, the corresponding decimal point in the product counter will lie between columns $2n$ and $2n+1$. It is clear that the product counter must contain 46 columns and the algebraic sign. As only 23 of these columns and the algebraic sign normally may be read out into the bus, it is the purpose of the plugging to make a suitable selection of the columns to be read out based upon the location of the operating decimal point. The plugging must be adjusted manually before the machine is placed in operation.

The second in a series of three articles, this article continues a discussion of the functions of the automatic sequence controlled calculator developed at Harvard University in cooperation with the International Business Machines Corporation. The calculator will carry out any selected sequence of the five fundamental operations of arithmetic (addition, subtraction, multiplication, division, and reference to tables of previously computed results) under completely automatic control. The functions considered herein are those of the multiplication and division registers and of the functional units.

Because the coding for multiplication must select the multiplicand and multiplier and deliver the product, it consists of three lines: multiply x in counter 56, code 654, by y in counter 18, code 52, and deliver the product xy to counter 13, code 431, (654, 761, blank), (52, blank, blank), (blank, 431, 7). Code 7 does not appear in the C column of the lines of coding selecting the multiplicand and multiplier and delivering them to the multiply unit. These are omitted because code B 761, the multiply code, is an automatic continue operation code and so replaces the 7's. No longer does each line of coding correspond to a single operation of the machine. The first line of coding delivers the multiplicand to the multiply unit, and turns over control of the calculator to a subsidiary sequence control within the multiply unit itself. The unit builds up and stores a multiplication table consisting of the nine integer multiples of the multiplicand. The multiply unit then signals the sequence control and calls for the multiplier. The process of multiplication is completed, within the unit, by withdrawing such multiples of the multiplicand as may be indicated by the multiplier and adding them together while shifting them to the proper columnar positions. Upon completion of this summation, control of the machine is turned back to the main sequence mechanism and the product delivered as indicated by the third line of multiply coding.

In the event that one or both of the factors involved in a multiplication are negative numbers, this fact is sensed and stored by the multiply unit. The factors then are treated as positive absolute magnitudes for use

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Design and construction of the automatic sequence controlled calculator was begun in 1939 at Endicott, N. Y., and continued until August 1944, when the machine was presented formally to Harvard University by T. J. Watson, president, International Business Machines Corporation. Commander Aiken wishes to express his appreciation to Mr. Watson for the support of International Business Machines Corporation during the years of development of the calculator and further to B. M. Durfee, F. E. Hamilton, and C. D. Lake, who, together with Commander Aiken, were coinventers of the machine. The relays, counters, cam contacts, typewriters, card feeds, and card punch employed in the calculator are all standard parts of tabulating machinery as constructed by International Business Machines Corporation.

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in the multiplication. Finally, the proper algebraic sign is appended to the product and it is read out directly or inverted as required.

The bus is used during the multiplying operation only three times. If properly timed, other operations involving the bus but not involving either multiplication or division, inasmuch as these operations are interconnected electrically, may be carried on during multiplication. Such operations are known as "interposed operations."

SPECIAL OPERATIONS

When the operating decimal point of the calculator is assumed to lie between columns 23 and 24, the corresponding decimal point in the product counter will fall between column 46 and the algebraic sign. For this case, the multiply unit is equipped with a special out-relay permitting the read-out of columns 1 through 23 of the product counter to the bus. The normal multiplying operation, with suitable plugging, delivers columns 24 through 46 of the product counter to columns 1 through 23 of the bus as usual. The use of the special low order product out-relay in effect provides the machine with 46 column products as obtained from 23 column factors.

One of the two pairs of ganged counters may be used in combination with this special product read-out to build up the product of two quantities, either or both of which may consist of 46 or fewer digits. The error in such a multiplication will be less than or equal to 2.7×10^{-46}. Thus, if the quantity stored across counters A and B is multiplied by the quantity stored across counters C and D, three multiplications, $A\times C$, $A\times D$, $B\times C$, will be performed and the products summed in the ganged counters. The product $B\times D$ is neglected as it is below the capacity of the machine.

Although the organization of the multiply unit is far more complex than that of the storage counters, nevertheless it is possible to alter the multiplying circuits to permit special operations. For example, it sometimes is required to print a function which has a very wide range of values. In this case, it is convenient to print a fixed number of significant figures together with an associated power of ten. The "normalizing register," in conjunction with the multiply unit, accomplishes this purpose by shifting a quantity so that its first significant digit appears in bus column 23, and recording the amount of the shift. The amount of shift, combined in a storage counter with a constant dependent upon the position of the operating decimal point, supplies the exponent required.

DIVISION

Division, like multiplication, requires three lines of coding. These read the divisor and dividend into the divide unit and deliver the quotient to its specified destination using the connections shown diagrammatically in Figure 2: divide x in counter 3, code 21 by y in counter 4, code 3, and deliver the quotient to counter 5, code 31, (3, 76, blank), (21, blank, blank), (blank, 31, 7).

After the divisor and dividend are read into the unit, they are shifted and stored so that their first significant digits appear in the highest column of the registers in which they are stored. The number of columns that the dividend was shifted and the complement on nine of the number of columns the divisor was shifted are added together in the "Q-shift" counter. A constant dependent upon the position of the operating decimal point is supplied to the Q-shift counter by a manually preset switch known as the divide switch. Since the Q-shift counter is not equipped with an end around carry circuit, the addition of a one in the units column completes the determination of the number of columns the quotient must be shifted when it is read out into the bus in proper decimal position. A one added into the units column of a counter to compensate for a missing end around carry commonly is known as an "elusive one."

As soon as the divisor is delivered and control of the calculator turned over to the divide unit, a table of the nine integer multiples of the divisor is built up and stored within the unit. When called upon the main sequence mechanism delivers the dividend. Under the subsidiary sequence control, the multiples of the divisor are compared with the dividend and the largest multiple less than the dividend selected. This multiple then is subtracted from the dividend while the digit defining it is entered in the quotient counter. The process of division is continued in this manner, successively comparing, subtracting, and shifting to the right. As the successive subtractions involve different columnar positions of the dividend counter, an end around carry cannot be provided. The subtractions are accomplished by means of complements on nine together with elusive ones introduced into the units column of each succeeding subtrahend.

If, upon comparison, the calculator finds that all multiples of the divisor are greater than the dividend or the remainder under consideration, a zero or "no-go" is entered in the quotient counter and a new comparison made one column to the right.

Division may be terminated after any desired number of comparisons by place limitation plugging and coding. The number of significant digits in the quotient will be either equal to the number of comparisons made or to this number less one (if the first comparison yields a no-go). The place limitation coding puts the accuracy of division under control of the main sequence mechanism so that the accuracy may be varied as desired within any given problem.

The quotient is read out into the bus through that part of the out-relay selected by the quantity standing in the Q-shift counter. If a negative number is shifted to

Figure 1. Multiply-divide and functional counters

the right, the out-relay also supplies the nines at the left required to complete the complement on nine of the quotient. The algebraic sign is determined by the methods employed in the case of multiplication.

Further, as in multiplication, the bus is used only three times during division, and is otherwise free for any interposed operations not involving either multiplication or division. It now should be clear that many of the electromechanical operations necessary to multiplication and division are identical, but controlled by two separate subsidiary sequence control systems.

ITERATIVE PROCESS FOR RECIPROCALS

Though it is not immediately evident, division consumes almost four times as many cycles of machine time as does multiplication and uses a great deal more apparatus. Obviously, this process is to be avoided whenever possible. Fortunately, an iterative process based on the Newton–Raphson[1] rule,

$$x_{n+1}=x_n-f(x_n)/f'(x_n),\ n=0,\ 1,\ 2,\ \ldots \tag{1}$$

is available for finding reciprocals. Let

$$f(x)=N-1/x \tag{2}$$

Then,

$$x_{n+1}=x_n(2-Nx_n) \tag{3}$$

defines a sequence, x_n, which converges toward the reciprocal of N. Each succeeding application of the iterative process roughly squares the error of the preceding approximation.

Suppose that in a given computation the values of the independent variable increase in an arithmetic sequence. Under these circumstances, the reciprocal of the nth value of the variable in general will furnish a good first approximation to the reciprocal of the $(n+1)$st value. Thus the process of division may be avoided with a considerable gain in the speed of computation. The application of equation 3 to the design of calculating machinery first was suggested by Aiken in 1938.[2] Equation 3 also provides the calculator with a means of dividing to an accuracy of 46 significant digits. The Newton–Raphson rule, by proper choice of $f(x)$, may be made to yield an iterative process for obtaining any fractional power of a given number so long as a suitable first approximation is available. This fact greatly extends the usefulness and speed of operation of the calculator without the inclusion of a single special electrical circuit.

On the other hand, the computation of the elementary transcendental functions may not be disposed of so easily. These require special registers as well as subsidiary sequence controls.

COMPUTATION OF LOGARITHMS

The method of computation of logarithms (Figure 3) within the calculator depends upon two equations,

$$\log\,(a\cdot b\cdot c\ \ldots)=\log a+\log b+\log c+\ \ldots \tag{4}$$

and

$$\log_e\,(1+h)=h-h^2/2+h^3/3-h^4/4+\ \ldots\ +(-1)^{n+1}h^n/n+\ \ldots \tag{5}$$

for $h^2<1$. The logarithm unit includes two counters known as the logarithm counter and the logarithm in-out counter, together with a subsidiary sequence control which governs these counters in conjunction with the multiply-divide unit. If it is desired to compute $\log_{10} x$, the coding in the main sequence control tape will read as follows: x lies in counter 39, code 6321, deliver $\log_{10} x$ to counter 8, code 4, (6321, 762, blank), (831, 4, 7), (blank, blank, 763). At the same time that x is read into the logarithm in-out counter, the code B 762 signals the logarithm subsidiary sequence control to take over the direction of the calculator. From the logarithm in-out counter, x is read to the logarithm counter so shifted that the first significant digit of x appears in the 23d column of the logarithm counter. The amount of the shift is recorded and its complement on ten entered in columns 22, 23, and 24 of the logarithm in-out counter, in which the decimal point now is considered to lie between columns 21 and 22. The computation of the

characteristic of x then is completed by adding $22-n$ into the logarithm in-out counter, the operating decimal point being between columns n and $n+1$. This quantity is supplied by a manually preset constant register known as the logarithm switch. For example, if the operating decimal point lies between columns 15 and 16 and $x=783.54210\ 50928\ 67954$, x is shifted five columns to the left on reading from the logarithm in-out counter to the logarithm counter. In this case, $22-n=7$. Hence, the characteristic of x is computed as $995+007=002$.

Now $\bar{x}=7.83542\ 10509\ 28679\ 54$ stands in the logarithm counter with the decimal point following its first significant digit, and it is only necessary to compute the mantissa of $\log_{10} \bar{x}$. This computation perhaps is explained best by a numerical example. Four successive divisions are performed:

$\bar{x}/7=1.11934\ 58644\ 18382\ 79142\ 85;$
$\bar{x}/(7)(1.1)=1.01758\ 71494\ 71257\ 08311\ 68;$
$\bar{x}/(7)(1.1)(1.01)=1.00751\ 20291\ 79462\ 45853\ 14;$
$\bar{x}/(7)(1.1)(1.01)(1.007)=1.00050\ 84698\ 90230\ 84263\ 30.$

Equation 4 becomes

$$\log 7.83542\ 10509\ 28679\ 54=\log 7+\log 1.1+\log 1.01+\log 1.007+\log 1.00050\ 84698\ 90230\ 84263\ 30 \quad (6)$$

The logarithm table relays store $\log_{10} N$ accurate to 21 decimal places, for N equal to: 1.0, . . ., 9.0, 1.1, . . ., 1.9, 1.01, . . ., 1.09, 1.001, . . ., 1.009. The internal logarithm sequence controls select the four logarithms called for by the first four terms on the right side of equation 6 and deliver them to the logarithm in-out counter for summation.

The last term of the logarithmic sum in equation 6 is of the form $\log (1+a10^{-4})$ where $a<10$. Writing $(1+a10^{-4})=1+h$, then $h<10^{-3}$. In using equation 5, six terms of the series are employed. Therefore, the remainder of the series will be

$$R<h^6(1+7h/8+7h^2/9+7h^3/10+\ldots)/7,$$
$$R<h^6(1+h+h^2+h^3+\ldots)/7,$$
$$R<h^6/7(1-h),$$
$$R<10^{-18}/7(0.999).$$

Clearly, the choice of four divisions and six terms of the series puts the error below the lower limit of the capacity of the machine. The series given in equation 5 is used by the machine in the form

$$\log_{10}(1+h)=(((((h c_6+c_5)h+c_4)h+c_3)h+c_2)h+c_1)h$$

where

$$c_1=M,\ c_2=-M/2,\ c_3=M/3,\ c_4=-M/4,\ c_5=M/5,\ c_6=-M/6:$$
$$M=\log_{10} e$$

The values of the c's also are stored in table relays and supplied to the multiply unit as directed by the logarithm sequence controls. One feature of these controls, not previously mentioned in this discussion, permits the multiplicand, h, and its multiples to remain stored in the multiply-divide unit throughout the evaluation of the series, thus saving considerable machine time.

After summing all terms of equation 6 in the logarithm in-out counter $\log_{10} x$ is read out into the bus through plugging inasmuch as it stands with its decimal point between columns 21 and 22 and must be shifted to conform with the operating decimal position.

The exponential function, or antilogarithm, is derived by a reversal of the process used to compute logarithms. The method of computation is dependent upon the equations

$$10^x=10^{i+.h}=10^i\cdot 10^{c/10}\cdot 10^{d/100}\cdot 10^{e/1000}\cdot 10^f \quad (7)$$

$$10^f=e^h=1+h+h^2/2!+h^3/3!+\ldots \quad (8)$$

where $h=f\log_e 10$.

The exponential unit includes the exponential in-out counter and a subsidiary sequence control governing this counter in connection with the multiply-divide unit. In order to compute 10^x, the main sequence control tape

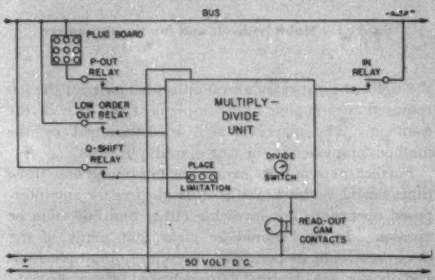

Figure 2. Multiply-divide unit

must read as follows: x lies in counter 27, code 5421; deliver 10^x to counter 20, code 53, (5421, 7621, blank), (blank, 741, blank), (832, 53, blank), (blank, blank, 731).

CALCULATION OF SIN x

The third electromechanical table contained within the calculator is that of the function, sin x. The method of computing sin x is based upon the equations

$$\sin(-x)=-\sin x \quad (9)$$

$$\sin(x+2n\pi)=\sin x \quad (10)$$

$$\sin x=\cos(\pi/2-x) \quad (11)$$

$$\sin x=x-x^3/3!+x^5/5!-x^7/7!+\ldots+(-1)^n x^{2n+1}/(2n+1)!+\ldots \quad n=1, 2, 3, \ldots, 10 \quad (12)$$

$$\cos x=1-x^2/2!+x^4/4!-x^6/6!+\ldots+(-1)^n x^{2n}/(2n)!+\ldots \quad n=1, 2, 3, \ldots, 10 \quad (13)$$

Inasmuch as the series of equations 12 and 13 are alternating series the remainder, R, will be less than the first term omitted. Assuming

$$x\leq\pi/4,\quad |R|<(\pi/4)^{23}/23!$$

Taking the logarithm of both sides of the inequality,

$$\log_{10}|R| < 22(\log_{10}\pi - \log_{10}4) - \log_{10}(22!)$$
$$< 22(0.498 - 0.602) - 21.050$$
$$< -23$$

Thus $|R| < 10^{-23}$ and the error in using these series for computation falls below the capacity of the calculator.

The sine unit (Figure 4) is composed of the sine in-out counter and subsidiary sequence circuits having control

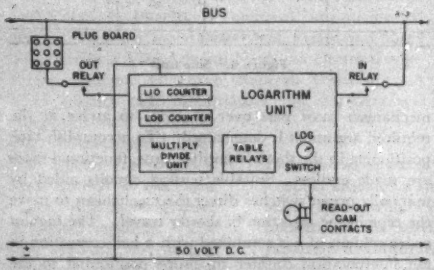

Figure 3. Logarithm unit

of this counter, the multiply unit and certain table relays providing the coefficients of the series together with other necessary constants such as $\pi/4$, $\pi/2$, $\pm\pi$, and 2π. The main sequence control tape dictates the computation of sin x by the coding: x lies in counter 14, code 432; deliver sin x to counter 40, code 64, (432, 7631, blank), (84, 64, 7), (blank, blank, 7321).

In order to compute sin x, it first must be determined in which quadrant x falls. The first operation in the sine sequence multiplies x by $1/2\pi$ (supplied by a table relay through plugging) at the operating decimal position. Then the product $|x|/2\pi$ is read into columns 1 through 23 of the sine in-out counter with decimal point at the operating position. At the same time, the algebraic sign of x is read into the 24th column of the sine in-out counter. Let $|\bar{x}|/2\pi$ indicate $|x|/2\pi$ with its integral part omitted. This integral part represents multiples of 2π which may be dropped by virtue of equation 10. Through plugging, $|\bar{x}|/2\pi$ next is read from the sine in-out counter to the multiplicand counter so shifted that its decimal point lies between columns 22 and 23. The algebraic sign of x remains stored in the sine in-out counter. The integer four, supplied by a table relay, is read to the multiplier counter. The resulting product is read into the sine in-out counter with its decimal point between columns 22 and 23. Four cases now may be distinguished:

(α) $0 \leq 2|\bar{x}|/\pi < 1$, x in quadrant I, sin $|x| \geq 0$
(β) $1 \leq 2|\bar{x}|/\pi < 2$, x in quadrant II, sin $|x| > 0$
(γ) $2 \leq 2|\bar{x}|/\pi < 3$, x in quadrant III, sin $|x| \leq 0$
(δ) $3 \leq 2|\bar{x}|/\pi < 4$, x in quadrant IV, sin $|x| < 0$

Which of these four cases appertain in the case of a specific value of x may be determined by sensing the integer in the 23d column of the sine in-out counter. The value of this integer together with the algebraic sign of x previously stored in the 24th column of the sine in-out counter completes the determination of the sign of sin x.

The procedure by which this is accomplished, and by which x is reduced to a first quadrant angle, now will be discussed. The quantity $2|\bar{x}|/\pi$ is multiplied by $\pi/2$ and when this operation is completed, the product, $|\bar{x}|$, is read into the sine in-out counter. During this multiplication, the sensing circuits on column 23 of the sine in-out counter order the following operations:

1. Reset all columns but the 24th of the sine in-out counter.
2. Case (α): $0 < |\bar{x}| < \pi/2$
$|\bar{x}|$ is read into the sine in-out counter directly;
Case (β): $\pi/2 \leq |\bar{x}| < \pi$
$|\bar{x}|$ is inverted when read into the sine in-out counter,
π is added into the sine in-out counter;
Case (γ): $\pi \leq |\bar{x}| < 3\pi/2$
$|\bar{x}|$ is read into the sine in-out counter directly,
$-\pi$ is added into the sine in-out counter,
a nine is added into the 24th column of the sine in-out counter;
Case (δ): $3\pi/2 \leq |\bar{x}| \leq 2\pi$
$|\bar{x}|$ is inverted when read into the sine in-out counter,
2π is added into the sine in-out counter,
a nine is added into the 24th column of the sine in-out counter.

Inasmuch as the sine in-out counter has no end around carry, and inasmuch as any digit other than a nine in the 24th column of this counter is the equivalent of a zero, the final algebraic sign of sin x now stands in the 24th column of the sine in-out counter. The reduced first quadrant angle, X, corresponding to the given value of x stands in the remaining columns.

Two cases remain to be distinguished:

(a). $0 \leq X < \pi/4$;
(b). $\pi/4 \leq X \leq \pi/2$.

After a sensing circuit has compared the value of X with $\pi/4$, in case (a), the computation proceeds by evaluating the series of equation 12. In case (b), $\pi/2 - X$ is formed and the series of equation 13 is evaluated. In either case, the result of the summation of the series is delivered to the sine in-out counter, columns 1 through 23, with the result that this counter then contains $|\sin x|$ and the appropriate algebraic sign.

The read-out of sin x to the bus for delivery to storage is through plugging, in order to shift the function to conform to the operating decimal position. The read-out is direct or inverted according as zero or eight on the one hand, or a nine on the other hand, stands in the 24th column of the sine in-out counter.

The logarithm in-out counter and the sine in-out counter commonly are used as "shift counters." These counters are equipped with pluggable and direct read-ins and read-outs. They may be used to multiply or divide by powers of ten. In addition, the pluggable read-

outs may be adjusted manually so as to permit selective read-out of the shift counters by means of which any m columns may be delivered to the bus while the remaining $24-m$ are suppressed. This selective read-out does not erase any part of the number standing in the shift counter. The read-ins and read-outs of these two counters have been placed under control of the main sequence mechanism by codes which are independent of the codes of the functional units of which the shift counters are themselves a part.

THE MECHANICAL INTERPOLATORS

With the aid of the electromechanical tables of $\log_{10} x$, 10^x and $\sin x$, all of the elementary transcendental functions, including the hyperbolic functions, may be obtained through the use of the operations of the calculator already described. In order to provide for inverse trigonometric functions, higher transcendental functions, and empirical functions defined by tabular data, the calculator is equipped with three mechanical interpolators.

The three interpolator mechanisms and their accompanying switches are on the left of the main sequence mechanism. The three units share in common the interpolation counter and the interpolation check counter. A function is introduced into an interpolation mechanism in the form of a perforated paper tape. This tape is similar to the main sequence control tape, but in place of commands to the calculator, contains coded successive equidistant values of the argument, each accompanied by the necessary interpolational coefficients. Any order of interpolation up to and including the 11th may be employed.

A function $f(x)$ is to be determined by means of Taylor's series. The independent variable, x, is considered as consisting of two parts, $x=a+h$, where a is an integral multiple of a power of ten. As four columns are provided for containing the value of a, it is clear that a functional tape may contain 10^4 arguments.

An interpolation is performed by evaluating the series

$$\begin{aligned} f(x) &= f(a+h) \\ &= f(a)+f'(a)h+f''(a)h^2/2!+\ldots \\ &= c_0+c_1h+c_2h^2+c_3h^3+\ldots \end{aligned} \tag{14}$$

in the form

$$f(x)=f(a+h)=((((\ldots+c_4)h+c_3)h+c_2)h+c_1)h+c_0 \tag{15}$$

TWO PARTS TO INTERPOLATION PROCESS

The interpolation process may be divided into two distinct parts. The first consists of positioning the functional tape, and the second of the computation necessary to the interpolation itself. For tape positioning, the argument, a, and the highest order column of h are delivered to the interpolation counter. The interpolator mechanism first reads the tape to discover the position at which the tape is standing. By subtraction in the interpolation counter, the number of arguments the mechanism must pass over in order to arrive at the required argument is determined. To accomplish tape positioning in the shortest possible time, functional tapes are made endless. Suitable sensing circuits aided by manually preset switches direct the mechanism to move the tape in the direction of shorter travel. The highest order column of h is combined with a half-correction in the interpolation counter to insure positioning to the nearest argument. As the tape steps, the number of arguments to be covered (stored in the interpolation counter) is reduced one for each argument passed and finally is reduced to zero.

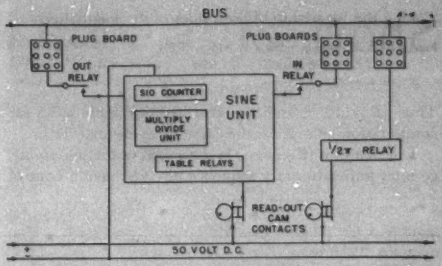

Figure 4. Sine unit

At the beginning of the positioning operation the required argument, a, is read into the interpolation check counter. At the end of the positioning operation it is transferred to the interpolation counter and used to check the position of the tape. If the tape is not in proper position because an impossible argument has been sent to the interpolation unit or because of faulty mechanical operation, the positioning mechanism will try a second time to find the required argument. The calculator is stopped and a red light turned on in the event that the positioning mechanism fails on this second try.

However, if the tape is found to be in the required position, the interpolation sequence control takes over command of the calculator. The quantity x again is read out of storage into the bus and the h part delivered by plugging to the multiply unit. Suitable corrections of h, such as nines to the left if h is negative, also are made by plugging.

The interpolation sequence control then evaluates the series of equation 15, while the multiplicand, h, is held constant as usual to conserve machine time. The coefficients, c_n, c_{n-1}, . . ., c_1, c_0, are read out of the functional tape and added into the multiplier counter under control of the interpolation sequence circuits.

Part III, the concluding portion of this article will appear in a subsequent issue.

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Short Survey of Japanese Radar—II

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Part II of a Japanese radar survey continues a report based on a study made by the United States Army which was particularly fruitful because of the obvious willingness of the Japanese to volunteer technical information, in spite of the difficulties of interrogating in a foreign tongue or through an interpreter unfamiliar with technical terminology. Because radar research was carried on separately by the army and navy in Japan, this article complements Part I's discussion of army radar with a summary of naval developments in the same field, as well as discussing general factors incidental to the manufacture and operation of radar equipment.

RESEARCH AND DEVELOPMENT of navy radar and allied equipment were vested in the electronics section of the Second Naval Technical Institute located near the Yokosuka Naval Base. The section was under the direction of Vice Admiral Nawa, an electrical engineering graduate of Tokyo Imperial University. A rather capable staff of physicists and engineers was employed, some civilians, some commissioned officers. Doctor Takeyanagi, a name known in television circles, was assistant chief of radar research. The staff received no outside assistance except for one Mr. Brinker, an unwelcome arrival from Germany who came to work in the laboratory at the direction of higher navy officials. The Japanese engineers felt that they were quite able to meet any radar problems that the navy might bring up. Thus the navy handled the majority of its own electronic research work, while in the army the tendency was to assign various projects to outside research agencies, such as the universities and the manufacturers.

The naval institute's electronics division employed 350 technicians including 80 engineers and scientists. The annual budget amounted to 100,000,000 yen* which included the costs of making prototypes for all land, air, and ship-borne communications and radar. The actual installation on ships, however, was not handled by the institute. The activities of the radar and communication department of the institute since 1940 include studies on tubes, materials, and test equipment; circuit development; and the testing of many components and complete radar and radio sets.

One development of some interest was apparatus *A*, by which the Japanese proposed to cause their own shells to explode at predetermined positions or heights by passing them through a strong beam of centimeter radiation. Although the Japanese did succeed in 1944 in generating ten kilowatts of continuous power at a 20-centimeter wave length, the idea failed because of the "lack of an adequate receiving apparatus."

The work conducted on magnetron research, under the direction of Captain Ito, a former student of Professor Okabe at Osaka University, is of particular interest. It may have come as something of a surprise to American intelligence officers and radar engineers that the navy was producing 10-centimeter magnetrons suitable for use in their ship-borne search sets as early as the fall of 1941. Thus, their microwave studies at that time were but a few months behind similar studies being conducted in the United States. In the succeeding years, however, American development outdistanced Japanese, inasmuch as the best the latter could do was to produce a tube giving about five or six kilowatts peak output at ten centimeters. Most recent magnetron researches by the navy had resulted, on an experimental basis, in tubes yielding 1.5 kw of pulsed power at 2.7 centimeters and "just observable" powers at 0.7 centimeter. Commercial research organizations displayed magnetrons for which they claimed outputs as high as 26 kw at 2.8 centimeters. A summary of navy radar developments is given in Table I.

NAVY WARNING RADAR SETS

Research and development work on type *B* (pulsed radar was begun by the Japanese navy early in 1941). The well-known type 11 (mark 1 model 1) 40-kw 100-megacycle set found at Attu and Guadalcanal was developed in the period between April 1941 and March 1942. The Japanese report that the first number 11 set was installed at Rabaul. Altogether, about 80

Based upon an official report, "A Short Survey of Japanese Radar," prepared by the Second and Third Operations Analysis Sections for Headquarters, United States Army Air Forces, from studies made by the Analysis Sections and the Air Technical Intelligence Group, Far East Air Forces, United States Army.

Acknowledgment is made of the services of Robert P. Featherstone, formerly captain, Army of the United States, who assisted in the collection of information contained in this survey.

Roger I. Wilkinson was operations analyst for the 13th and Far East Air Forces from October 1943 to December 1945. His assignment after the fall of Japan was to study all phases of Japanese electronics and radar from research to operations. He now is back with Bell Telephone Laboratories, New York, N. Y.

* In purchasing power roughly equivalent to 100 million dollars in the United States.

Figure 1. Ship-borne 10-centimeter radar set number 22 for surface search

Under bench, left to right: Antenna control handles, rectifier
On bench, left to right: Receiver, indicator for warning, receiver control panel, transmitter, transmitter control panel
On wall: Antenna azimuth indicator

of these large early-warning sets were manufactured.

Soon after, work was begun on a smaller set which would not require the building of the large number 11 sets on distant islands, and several portable models were developed. Set number 12, of 5-kw power and working at 20 megacycles, appeared at the end of 1942; it later was adapted for ship-borne use also although throughout its life it was troubled with frequency instability. Set number 13, 10 kw at 150 megacycles, followed as a very lightweight unit in 1943, while simplified number 13, that is number 13K, was making its appearance just as the war ended. In the fall of 1944 when the B-29 raids began in earnest, the Japanese decided they needed a set which would give them longer range warning than any of the sets then in use. A long wave 6-meter set was "crash-engineered" and then built in three weeks. Three of these sets eventually were installed, two on the southern shores of Honshu, and the third at the very southeastern tip of Kyushu. Ranges obtained on high flying B-29's were consistently of the order of 300 kilometers.

The first of the long line of number 22-type ship-borne 10-centimeter search sets was completed in June 1942. The transmitter is powered by an M-312 magnetron, the anode of which is water-cooled by a motor-driven pump. The tube delivers a peak power of approximately six kilowatts with 11,000 volts applied to the anode. Power is transmitted through circular cross section wave guide to a horn antenna. A separate horn is used for receiving to obviate the loss and complication in a transmit–receive (TR) tube to accomplish electronic switching. A blocking oscillator provides the 10-microsecond keying pulse at a rate of 2,500 per second under the control of a tuning fork. The receiver is a superheterodyne with crystal detector and magnetron M-60-S as local oscillator. The intermediate frequency is 14.5 megacycles, the total receiver gain amounting to 120 decibels. The display is on two type-*A* cathode ray tubes. One tube called the "indicator for warning" shows all target echoes up to 60 kilometers. Range pips generated by shock exciting a crystal appear every five kilometers. A 3-microsecond range pulse is moved along as the range crank is turned. The second, or "range operator's oscilloscope" gives an expanded view

Table I. Radar Equipment Developed by the Japanese Navy

Power and range figures given indicate maximum for each classification

Classification	Number of Types Studied	Objectives	Frequency (megacycles) or Wave Length (centimeters)	Power Output	Range
Land-based radar	22	For use in antiaircraft warning, searchlight and antiaircraft fire control, altitude measurement, and identification of aircraft	2 at 60, 6 at 100, 5 at 150, 7 at 200, 2 at 500 megacycles	to 100 kw	to 450 kilometers
Ship-borne radar	20	For use in antiaircraft and antisurface warning and fire control	4 at 150, 6 at 200, 1 at 500 megacycles; 1 at 28, 8 at 10 centimeters	to 30 kw	to 100 kilometers
Air-borne radar	11	For use in patrolling and searching, aircraft identification, altitude measurement, and path finding	6 at 150, 1 at 250, 1 at 340, 2 at 500 megacycles; 1 at 10 centimeters	to 20 kw	to 150 kilometers
Land-based, ship-borne, and air-borne radar counter measures	9	Search receivers to determine data on enemy radar	3 centimeters–4 meters	Receivers only	

of about 1,000 meters of the range as selected by the range crank. A magnifying glass in front of the oscilloscope gives it a size equivalent to a 5-inch tube. The true range is read on a dial when the target pip's leading edge is set just even with a vertical line inscribed up the face of the tube. The range obtainable on a battleship was of the order of 25 kilometers. This set was agreed by army and navy alike to be one of the most satisfactory radars used by the Japanese forces. Members of the navy laboratory assembled a 22 set at their Tsukishima test area in Tokyo's eastern suburbs for viewing by United States Army air personnel. Excellent definition was obtained on targets in Tokyo Harbor. Figure 1 shows a bench set up with the transmitter, receiver, and indicator for warning. Figure 2 shows the range unit.

A somewhat simplified version of number 22 called modification-3 was installed in the conning towers of submarines. It used two horns mounted side by side. Presentation was on a single *A*-type 75-millimeter oscilloscope. Range was about ten kilometers on a battleship.

For ship-borne air warning a modification of the number 12 land-based set (renamed number 21) was used, and the number 13 land-based set also was adapted for the same purpose.

The first development work on air-borne radars was done by the navy in November 1941. It resulted in a patrol and search set (number H-6) working at 150 megacycles. During the years that followed, some 2,000 of these sets, which gave excellent satisfaction, were manufactured. The H-6 eventually gave way to the lighter and more compact FK-3 in the latter months of the war.

The navy well appreciated the desirability of obtaining better definition than could be realized from the 150-megacycle sets used for sea patrolling if they were to be able to do radar bombing. Some work was done in an attempt to adapt the 10-centimeter number 22 ship-borne set for this purpose, but the project was unsuccessful. Meanwhile, design specifications on a 10-centimeter air-borne search set called the Rotterdam Gerate had been received by radiotelegraph from Germany. (It now is believed the data came from an early British H2S set shot down by the Germans over Rotterdam.) On the basis of the received data, the navy

Figure 2. Range unit for type 22 radar

electronics laboratory set out to build equipment. The result was the number 51, or Pathfinder, set which is roughly equivalent to the American ASG or SCR-717-B. It is a 10-centimeter magnetron powered set with a north stabilized 150-millimeter plan position indicator oscilloscope tube. The magnetron is the M-314, and can be seen inserted inside the toroidal-type magnet in Figure 3. Arrangement is made for a lubber line to show the heading of the airplane at any instant. A second *A*-display tube reads altitude. A small M-60-S magnetron is used as the local oscillator. The antenna is the rotating cut parabola type and carries a folded antenna with a parasitic dipole reflector in front of it. Preliminary flight results showed that shorelines could be distinguished at only 20 kilometers, a figure far below what had been hoped.

NAVY LOCATOR-TYPE RADAR SETS

The first navy ground-based locator-type radar was based on the American SCR-268's captured at Corregidor in the spring of 1942. Research on the resulting S-3 antiaircraft fire control set was begun in August 1942 and concluded a year later. The Sumitomo Company was provided with drawings of the desired equipment from which they produced about 80 sets, at the very slow rate of five per month. The close resemblance of the copy to the original, the American set, may be

Table II. Nihon Musen Magnetron Characteristics

Tube Designation	Tube Characteristics					
	Anode Voltage	Peak Anode Current	Wave Length (centimeters)	Peak Power Input (kw)	Peak Power Output (kw)	Magnetic Field Gauss
Transmitting:						
M-312	11,000	2 a	9.83–9.92	22 peak	6.6 peak	1,000
M-314	11,000	5 a	9.83–9.92	55 peak	17 peak	1,000
S-60	8,000	7 a	5.2	60 peak	18 peak	2,100
S-51	12,000	6 a	3.15	72 peak	22 peak	2,200
Receiving (beat frequency oscillator):						
M-60	210 ± 20	17 ma ± 0.1 (cw)	9.83–9.92	—	—	690
M-2643	540	1.5 ma (cw)	2.8–10.0 (Nominal 3 centimeters)	—	—	4,000

recognized in Figure 4. The Japanese had no better luck with these sets in hitting anything than the United States Forces had with the SCR-268. Meanwhile production was started on a searchlight control set L-1 built along the lines of the British searchlight control data obtained at the fall of Singapore. Attempts also were made to adapt the latter for fire control purposes, resulting in the S-23 set. However, the directional accuracy was not good enough, and after making a few sets, the project was abandoned.

Difficulties in building and maintaining the S-3 resulted in the design of a simpler 200-megacycle antiaircraft control set known as the S-24. Inasmuch as this set had both greater range and greater accuracy than the S-3, it became the navy's standard land-based fire control radar equipment. However, its accuracy was still very poor as judged by American standards and, with its susceptibility to jamming, it was thoroughly inadequate to handle the pressing anti-aircraft fire control problem.

The navy's initial answer to the jamming problem, as well as the relative inaccuracy of the S-3 and S-24 sets, was to build a higher-frequency set. This was done in the experimental number 61 which, at a wave length of 60 centimeters, has much the appearance of the Small Wurzburg. The navy also had spoken for a share of the production from the army's Wurzburg program.

For ship-borne and coastal defense fire control the navy adapted the number 22 set by switching the receiver alternately to each of a pair of horns with slightly diverging axes. This produced a pair of lobes with a spread of about six degrees. The received signal pips were matched for height on a suitable bearing cathode-ray tube to obtain an azimuthal accuracy in the order of plus or minus one-half degree. Experiments also were made with large parabolic reflectors. Here the dipole antenna was oscillated rapidly in a horizontal slot located roughly at the focus of the parabola.

NAVY GROUND CONTROLLED INTERCEPTION

The navy plan for controlling friendly fighters was quite similar to that proposed by the army. A ground interrogator with broadband antenna enabling it to operate anywhere from 145 to 155 megacycles trips the transponder in the airplane, which replies at a slightly different frequency (up to three megacycles difference). Radar set number 62 obtains range on an *A*-oscilloscope and shows bearing on another oscilloscope by matching pips through a mechanical lobe-switching device. It may be noted that the identification-friend-or-foe transponder in the airplane, when not being employed for ground controlled interception work, sweeps a band of 150 plus and minus five megacycles and replies on the interrogation frequency, so that any 150-megacycle radar set such as the navy's number 13 can identify friendly airplanes by the fluctuating increase of the target return at regular intervals. This corresponds exactly to the old American mark 2 identification-friend-or-foe system. For locating the foe airplane, the navy was developing a long-range (200-kilometers) 100-megacycles-per-second lobe-switching radar set to be called number 63. As with the army's proposed scheme for making interceptions by means of separately tracing the friendly airplane and the foe airplane with radar equipments having relatively poor bearing accuracy, it would seem highly likely that the navy's plan would have given very disappointing results unless exceedingly skillful operators were employed.

The navy was developing two night fighter radars at the time the war ended. The 500-megacycle number FD-2 set had a presentation giving azimuthal corrections only with an oscilloscope indication similar to that of the American SCR-521. The other set, working at 150 megacycles per second, was known as Gyoku-3. It employed an unusual fixed antenna built in two forward-facing layers. By feeding them through a rotating goniometer-type coil, a rotating forward lobe was generated and the corresponding display was shown on a plan position indicator oscilloscope. The definition in this set would seem to be very poor, inasmuch as the beam is some 70 degrees in thickness. Japanese navy engineers insisted, however, that such a thick beam is needed or the entire area in front of the airplane could not be searched adequately. Apparently the idea of rapid scanning by a very narrow forward-looking pencil of radiation had not appeared to them to be practicable.

Figure 3. Detail of transmitter of 10-centimeter air-borne "Pathfinder" search set showing electromagnet with magnetron inserted axially

NAVIGATIONAL AIDS

Both the army and the navy had developed low altitude frequency-modulated altimeters, which they claimed had been of good service during low altitude torpedo bombing attacks on enemy shipping. The army also had a high altitude pulsed altimeter, but it gave so much trouble and read so erratically that the flyers would not rely on it. Neither the army nor the navy had any program for vectoring home lost pilots by means of radar plots. No mention of the use of the identification-friend-or-foe sets in the airplanes to extend their locating coverage for this purpose was made in discussions of the various associated equipments.

The army had plans drawn up and equipment partly installed for a simple hyperbolic navigation system very similar to Loran developed by the United States. The idea for this, although denied by the army, was said by navy personnel to have come from Germany. The equipment carried in the airplane was much simpler than in the American version. The radio operator timed, on a stop-watch, the interval taken by a carefully controlled drift pulse from one of the two ground stations to travel between coincidence with the two regular pulses from the ground stations. Very likely the accuracy does not compare with that obtained by American sets, although it may well be good enough to be of great value to airmen.

RADAR MANUFACTURERS

The production of radar equipment for both the army and navy was contracted for by a relatively few large manufacturing concerns, who in turn were supplied with parts and minor assemblies by a myriad of small producers. The method of handling was not unlike that used in the United States. The three principal Japanese radar manufacturers were the Nihon Musen Company, the Tokyo Shibaura Denki, and Sumitomo Tsushin Kohgyoh. Each maintained a staff of electronic research workers recruited mainly from the company's peacetime engineers, physicists, chemists, and metallurgists.

Figure 4. Rear view of 8-3 radar (at Chogo)
Note resemblance to American SCR-268

The policy of secrecy enforced by both the Japanese army and navy was a great handicap to production. Often in the same plant similar sets were being developed by company engineers for the two branches of the service, but they were not permitted to exchange the slightest information. For example, the Nihon Musen Company's main plant was divided carefully into two parts, one for manufacturing army equipment and the other for navy equipment. This military policy was criticized strongly by all company officials who saw not only the wastefulness of building two sets to do the same work, but the even more critical loss in engineer and research talent caused by such duplication of design.

The Nihon Musen Company, an affiliate of the German Telefunken electrical interests since 1923, employed some 16,500 workers in its four plants at Mataka (Tokyo suburb), Nagano, Ueda, and Suwa. None of these plants was injured by American bombings. The research section, located at the Mataka plant, had two divisions, one on vacuum tubes which employed 60 scientists and engineers, and one on general matters which employed 40 engineers. Nihon Musen's vacuum tube development under the leadership of engineer Shigeru Nakajima was outstanding. To him is given much credit for the design of the successful magnetrons used in the army and navy's most advanced radar equipment. Experimental magnetrons down to 0.7-centimeter wave length had been built, but their lamp load method of measuring powers was inadequate to determine output at such ultrahigh frequencies.

The principal characteristics of Nihon Musen's later magnetrons are given in Table II.

Perhaps Nihon Musen's most interesting commission was, in 1945, to build as quickly as possible three exact copies of the German Small Wurzburg, known in Japan as Tachi-24. These were to be used as models for building 50 sets by the three large radar manufacturers to fill the first joint order of the army and navy. The first of the models was within one month of completion when the war ended on August 15.

Tokyo Shibaura Denki is the Japanese counterpart of the General Electric Company in the United States, and before the war was affiliated with that company and others for the exchange of certain technical information. The company operated five plants located in Tokyo, Kawasaki, Fuji, and Yobe, with a total of 27,000 employees at their peak of production. The three largest plants which were in the south Tokyo area were estimated to be 70 per cent destroyed by fire and bombings. The general and electronics research laboratories, located in the Koikawa Cho plant both were destroyed completely. The general research section was comprised of 100 engineers and scientists, while the electronics laboratory employed about 150 research workers.

In the Tokyo Shibaura electronics laboratory considerable effort was being expended to produce magnetrons at higher and higher frequencies. A 15-centimeter magnetron for the Tase-2 set was the laboratory's highest frequency tube actually in production. However, the research director, Doctor Hamada, had built experimental all-metal types down to three centimeters. For example three of these models shown in Figure 5 have the following claimed performance:

Three centimeters—1-kw peak (air-cooled).
Five centimeters—3-kw peak (air-cooled).
Nine centimeters—10-kw peak (air- and water-cooled).

In general, electromagnets were used for obtaining a strong field for the magnetrons, although experiments with materials for permanent magnets had yielded fields up to 2,000 gausses. Shortages of nickel and cobalt were given as reasons for not developing the permanent magnet program to a fuller extent.

For local oscillators, Tokyo Shibaura engineers had experimented with positive grid Barkhausen tubes to work with crystal detectors. They had tried to build power klystrons five years or more ago at about 20 centimeters but without much success. More recently they had been working with klystrons for receivers at three, five, and ten centimeters.

The Sumitomo Communications Industries Company in peacetime is Japan's leading manufacturer of telephones and automatic and manual switchboards, as well as much wireless and electric testing equipment. It is owned partly by the International Standard Electric Company. Its seven plants in Japan employed 32,500 persons. About half of these were at the Tamagawa plant in Kawasaki which was about 60 per cent destroyed by bombing. The Ikuta research laboratory, 12 miles southwest of Tokyo, is one of the largest electronics research groups in Japan, with a staff of 650 engineers and assistants. During the war most of the talent was devoted to radar research in one form or another.

In November 1944 Tama Institute directed the Sumitomo Company to develop and build a 5-centimeter air-borne search radar set, with the single specification "with as much power and range as possible." At that time they did not know that the American B-29's were equipped with 3-centimeter radar sets or they might have attempted that wave length. The tube research section finally succeeded in devising a 5-centimeter magnetron with equalizer ring which developed one kilowatt of pulsed power, but not until Tama Institute had made available, early in 1945, several recovered magnetrons from APQ-13 sets in crashed B-29's. (A number of these were in operating condition, although the Japanese never obtained more than five kilowatts from them.) The antenna and radio frequency "plumbing" were influenced considerably by American design. At the same time a velocity modulated tube with variable frequency was developed as a beat frequency oscillator to work in the receiver. The size of the metal cavity clamped or soldered to the flanges passing through the glass envelope determines the resonating frequency, which can be varied up to plus or minus five per cent by mechanically compressing the cavity. The voltage on the repeller is varied until maximum output is obtained.

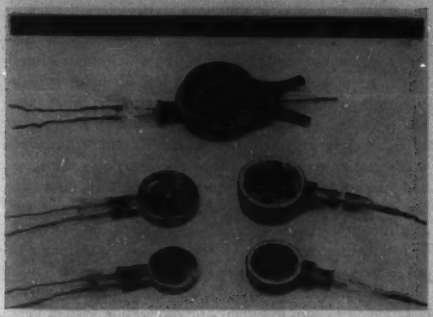

Figure 5. "Rising Sun" type magnetrons built by Tokyo Shibaura Company

Wave lengths from top to bottom: 9 centimeters, 5 centimeters, and 2.7 centimeters

ARMY-NAVY LIAISON

The great majority of the radar sets installed on the islands which the Japanese invaded were navy types and were operated by navy personnel to protect their own installations. In this way the navy became experienced in early-warning activities near the beginning of the "Pacific War," as the Japanese call it. In the Japanese homeland however, the army was charged with the responsibility for general air raid warning and covered the islands with a network of stations of both types *A* and *B*. There was an almost negligible liaison between the army and navy all the way from research and design through manufacture, installation, and operation. As a result, in Japan proper the navy practically duplicated the army's early-warning coverage, but the information so obtained was used almost exclusively for alerting their own air and sea bases and such antiaircraft and fighter protection as they had available.

The severe loss in efficiency caused by the unwillingness of the two branches of the service to exchange ideas or use any of the same equipment was pointed out strongly by manufacturers, and by others in academic circles who had no military loyalties to defend. The danger of this condition finally was appreciated in certain high quarters, and a joint army–navy committee was set up in August 1943 to correlate the army and navy

Figure 6. The Tokyo Information Center viewed from the outer moat of the Imperial Palace grounds

The bedspring antennas visible are part of an experimental 60-centimeter frequency modulated communications set

programs. Although the committee met once a month, its ineffectiveness is seen by the fact that it could not obtain agreement between the army and the navy even on using the same identification-friend-or-foe set. The navy adopted a set with transponder sweeping from 145 to 155 megacycles, while the army's set in the airplane received at the spot frequency of 184 megacycles and retransmitted at 175 megacycles. Thus the army could not distinguish Japanese navy airplanes from enemy airplanes, nor could the navy do better for the Japanese army airplanes, and the jealousies between the two services were such that neither seemed to care! The chief contributions of the army–navy joint committee seem to have been to unite the two services on ordering of the Small Wurzburg sets and to obtain agreement that the next air-borne set following the navy's number 51 and the army's Taki-14 would be a jointly sponsored 5-centimeter equipment. Some question exists even as to the co-operation present on this last project, inasmuch as, at the close of the war, the army was experimenting actively with 5-centimeter sets (Taki-34) with apparently no participation by the navy.

JAPANESE RADAR COUNTERMEASURES

Both the army and the navy appreciated the need for knowing what manner of radar sets was being used against them. Both had developed a line of search receivers with various means of displaying or recording the signals picked up. Some were equipped with oscilloscope presentations whereby homing on a signal was possible. The army, in addition, had built a pair of "wave disturbers," Taki-8 and Taki-23, which were spot jammers of either the impulse or continuous wave type, covering the wave lengths from 7 meters down to 80 centimeters. A magnetron jammer especially designed for the *X*-band of the B-29's was under construction.

Repeated questioning of army and navy radar engineers brought forth emphatic denials that the Japanese ever had installed a captured American identification-friend-or-foe set in their ships or airplanes. This makes very difficult an explanation of certain observed instances where Allied Forces were sure that their identification-friend-or-foe system had been compromised. The upper end of the navy identification-friend-or-foe M-13 sets' sweep at 155 megacycles nearly would overlap the lower edge of Allied frequencies. However, the Japanese navy maintained that development of this set

Figure 7. View of the north wall of the operations room in the Tokyo Information Center

Visible are part of the ground observer display map, the type A detector display board, and part of each of the banks of ground observer display panels

was completed only in July of 1945, and that of the 50 sets manufactured, none was yet in operational use. The army equipment, with split interrogating and responding frequencies, should not have shown up on American radar equipments at all.

EFFECTIVENESS OF ALLIED JAMMING

According to all accounts, Allied jamming was so effective that, after May 1, 1945, it was impossible for Japanese antiaircraft guns to shoot unless they had visual tracking. This meant that American bombers had to be picked up first by searchlights which themselves were having a great deal of trouble finding the the target because of the very same electronic jamming on their 200-megacycle frequency.

Inquiry revealed that Allied use of "window" (metal foil strips dropped to create phantom targets), while effective, did not cause nearly the difficulty that the electronic jamming produced. Skilled operators at such places as Kobe were able to distinguish airplanes from the false window targets and to give some rough indications of the locations of the airplanes. However, the electronic jamming created a sea of grass over the entire oscilloscope, and it was impossible to distinguish targets of any kind.

RADAR TRAINING

Both the army and the navy had organized radar training schools for operators and maintenance men. The army's school at Tachikawa was equipped fairly well with several of each type of radar set used by army forces, and could accommodate about 1,200 students at one time. Radar operators here received three months of instruction, maintenance men six months. The navy operated a very large and exceedingly well-equipped school at Chogo, just south of Atsugi airdrome. Courses ran from four to ten months for the 7,000 students who could be accommodated at one time. This school compared very favorably with those set up in the United States for the same purpose.

JAPANESE AIR DEFENSE SYSTEM

The Japanese air defense system was an elaborate combination of ground observers and type *A* and *B* radar sets. Partly on that very account, it was unwieldy and slow to function. Certain features of the amazingly complex fighter control centers were conceived and built very well. The display of radar information on a lighted gridded map without the use of cluttering stands, for instance, was good. But the equally important ground observer reports appeared at another location and in a quite different presentation form from which no flight tracks were plotted. In addition, there was the problem of using the data from antiaircraft radar systems which came in over a loudspeaker and were plotted on a third display position. It must have been impossible for an ordinary human controller to co-ordinate and filter in his mind all of the information arriving during a large raid. Figure 6 shows a view of the Tokyo Fighter Control Center, located just inside the outer moat of the Imperial Palace grounds. Japanese military officials flatly denied that the control center had been placed there purposely to increase its immunity to Allied bombs. Whether intentional or not, the effect was the same inasmuch as American forces carefully avoided bombing the palace area. Figure 7 shows part of the operations room.

There was also apparently little or no system by which fighters could be directed properly to get into an advantageous position for making an interception as the B-29's arrived, even though in most cases early warning of an hour or more was available. Very poor liaison was maintained between the army and the navy information centers. It would have been a long step forward to have consolidated the two early-warning systems and to have had all stations report to a single information center in the area. Full information would have been had, then, with half the expense and confusion.

Through the fighter control center means for locating friendly aircraft could have been arranged easily by the simplest of direction finding chains. This method would have aided them greatly in developing the techniques necessary for conducting interceptions well before raiders reached the target. Moreover, it would have provided a means for locating pilots in distress and directing them back to friendly bases. As it was, pilots running out of gasoline over the ocean could not be aided inasmuch as their position was too indefinite to warrant sending out rescue craft. This fact further aggravated the scarcity of good night pilots.

CRITIQUE OF JAPANESE RADAR

All in all, it must be said that the type *A* plus the type *B* equipments gave entirely adequate early warnings of B-29 raids. Occasionally, single bombers flying low and fighters in small formations could slip through the net, but not so often as to present a serious problem. The far-flung system of ground observers tended to fill in any warning shortcomings of the radar equipments.

The good Japanese air raid warning service was useful in that it gave people a chance to seek shelter in time to save their lives. At the same time, the resistance offered to the approaching bombers by antiaircraft fire and by fighter interceptors was pitifully small. This was very largely because the Japanese did not have:

1. Sufficiently accurate fire control radar.
2. Ground and air-borne equipment adequate for ground controlled interception work.
3. An effective system for using what radar they did have of this type.

A considerable part of the responsibility for the poor

showing made in resisting American raids must be attributed to the lack of technical development by the Japanese of radar sets accurate enough for good fire control or for fighter direction, that is, the equivalents of the United States forces SCR-584 and SCR-527 and, of course, the AN/CPS-1 (or MEW).

The men in charge of electronics research in both the Japanese army and navy well were aware of their deficiencies in fire control and air-borne interception radar. They were pressing their own engineers and those of industrial concerns to overcome these gaps in their defenses at the earliest possible moment.

Much of the Japanese-designed radar equipment examined appeared to be crude both electrically and mechanically in comparison with the later United States sets, although certain equipments were constructed beautifully with no skimping on materials. There is some doubt as to whether the Japanese could have duplicated successfully American modern fire control and ground controlled interception radars even if they had captured them. As a matter of fact, they had obtained fairly good specimens of American identification-friend-or-foe sets and the APQ-13 from B-24's and B-29's, but, generally stated, they never had been able to put them into complete operation. Admiral Nawa, head of Japanese navy electronics research, stated that their greatest shortcoming in comparison with American radar design was their inability to turn out a high-powered centimeter transmitting tube. Most students of the situation will agree, although, as has been noted, independent Japanese research was well on the way.

Very severe criticism should be leveled by the Japanese people at those military leaders who insisted for so long that army and navy research, development, production, and operation be kept entirely separated. Equally as serious was the neglect to organize the full scientific power of the nation for war research. All this, of course, is realized now by Japanese ex-military leaders. They would not be likely to commit the same mistake another time.

Report from Bikini

H. H. SKILLING
FELLOW AIEE

An AIEE member who was present at the recent atomic bomb tests at Bikini reports his reactions to the tests to the Institute. Full texts of the reports of President's Evaluation Commission and the Joint Chiefs of Staff Evaluation Board are included.

AS ONE of the members of the American Institute of Electrical Engineers invited to witness the atomic bomb tests at Bikini, may I take this means of making a short report to the Institute?

Since returning from Bikini, I most frequently am asked two questions: were the tests worth while, and what are the general indications for the future? The best answers I can give are not my own alone, but reflect my views as influenced by the 22 other American observers in the same group and the 21 observers representing nations of the Security Council of the United Nations.

The tests were very much worth while. Every engineer can appreciate the importance of tests made under conditions as near those of actual practice as feasible. Extrapolation from small-scale tests, or from data gathered under dissimilar conditions, is a helpful guide; but whether the subject is machinery or lightning or atomic bombs, information from full-size tests is of the greatest aid to the designer. It is evident that if the United States is to have a navy at all it must have an effective navy, and it is only reasonable that its military and naval designers should be supplied with all information that can be obtained. If there is to be another major war it will be an atomic war (this is the opinion of our group) and if we are to have a navy it must be prepared to resist atomic weapons.

It must not be thought that the purpose of the tests was to gather data for pure science. This may come as a by-product, but the major object was military and naval information. Plans for the tests were made and carried out carefully, and the records cover not only such obvious factors as pressure and temperature of the blast, but also collateral matters including effect on radio propagation, wave action on the beaches, and possible results on fish feeding on radioactive organisms in the lagoon. Automatic recording equipment was used for a great many purposes, and full interpretation will require a large amount of careful work.

Regarding the future, the atomic bomb is surely a

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terrific weapon. It is highly destructive through a radius of about 1,000 yards and only very strong structures can survive the shock and heat of the bomb within this distance. A battleship, for example, may not be destroyed at a distance of a few hundred yards, but it will receive considerable damage. Beyond 1,000 yards damage is relatively slight: light structures are thrown down, windows are broken, fires may start in readily inflammable material.

Within 1,000 yards there would be heavy casualties among any persons exposed directly to the blast of a bomb exploded in air, and, in addition, the fatal effects of radioactivity extend 1,000 yards or more from a bomb exploded either in air or water. For the under-water bomb, radioactivity may be serious at a distance of several miles, resulting from drenching with radioactive water.

Excellent statements of the results of the bomb exploded in air may be found in the "Report of the President's Evaluation Commission" and the "Report of the Joint Chiefs of Staff Evaluation Board," both released by President Truman on July 11, 1946. (These reports, in full, are appended to this article.) The observations of our unofficial group are in full agreement with these reports.

Regarding the possibility of maintaining peace, our scientists and military men, both American and from the United Nations, were in very general agreement on a number of points. First, people of each nation must come to know the people of other nations, to understand their problems and their points of view, and to sympathize with their troubles. Then it will be possible to take steps to remove economic and political causes of discord. Then it will be possible for political machinery such as the United Nations organization to be effective.

It was the expressed hope of the group of observers that all educated and enlightened persons will promote good feeling between the people of our country and the people of other countries by all possible means. Effective means mentioned include travel, traveling fellowships, reading, speaking, and whatever may be done to encourage calm and thoughtful interpretation of the daily news. But even in the present state of incomplete understanding and sympathy the United Nations organization is of great value and must be given every support.

Report of the President's Evaluation Commission

Dear Mr. President:

Your Evaluation Commission, divided between positions at sea and in the air, witnessed the first Bikini test, at 33 seconds after 9:00 A.M. local time on July 1, and has since completed a survey of the damage. The second test, wherein the bomb will be exploded under the water, will in some respects be of even greater interest, for it will have no precedent. The report of your Commission required by its directive of May 18 must await assembly of considerable data deriving from instrumental and photographic measurements and analysis of fission product samples. However, we believe that it lies within the scope of your directive and may be of possible assistance to you, to submit, now, the following brief observations made from the layman's point of view, but with such accuracy as is presently available:

The organization and execution of the operation was magnificently handled and has commanded our continuous admiration. The bomb was dropped under favorable weather conditions about 30 seconds after the time set. The greatest credit is due Admiral Blandy and the officers and enlisted personnel of both services who, with scientists and other civilians, have served and are serving under him with a display of team work that must be seen to be fully appreciated.

Their conservatively safe distance from the burst led many observers to entertain an initial opinion that the bomb employed was somewhat under par. It is now, however, safe to state that the energy was of the same order of magnitude as in the case of previous atomic detonations, between the highest and the lowest of this bomb's three predecessors.

The accuracy of the drop was such that the explosion occurred within the area included within the allowance for the probable error of the elevation of drop, and detonation was probably within 100 feet of the chosen altitude. Nevertheless the explosion actually occurred several hundred yards west of a point directly above the target ship Nevada, and therefore entirely west of the closely spaced array of capital ships.

There were 90 targets anchored in the lagoon when the bomb exploded. These were not in battle formation but were placed in positions to give the largest amount of desired technical information with especially close concentration around the center target point. Those ships anchored a mile or more from the point of drop largely escaped injury. Those within a mile were sunk or suffered damage varying with the distance from the point of detonation and with the type of ship construction. On explosion, a destroyer and two transports sank promptly. A second destroyer and the Japanese cruiser Sakawa sank within 27 hours. The light carrier Independence was gutted with fire and resultant explosions. The submarine Skate was damaged heavily and later towed away. All of these were near the point of explosion. The other ships, including the only two capital ships which were within one half a mile of the detonation, received damage that would require more or less complete overhaul and in most cases repair at major bases before they could again be used for combat. A study of this damage will point the way to changes in design which should minimize the damage from blast and heat. Beyond these ships there was extensive damage to superstructure, radar, and fire control. Had the ships within the damage area been manned, casualties and psychological injuries would have required a large percentage of replacements. Until the readings of complex instruments and the future life history of animals within the ships have been determined no accurate appraisal of potential damage to human life within the ships can be made.

No wave or blast damage could be noticed on Bikini Island which is approximately three miles from the point of detonation.

We are of the unanimous opinion that the first test amply justified the expenditure required to conduct it and that the second test is equally desirable and necessary. You made a wise decision when you approved the plans for these tests and they have been carried out with extraordinary skill, diligence, and ingenuity. The test just completed has again proved that the atomic bomb is a weapon of terrific power when used on land or sea.

Most respectfully yours,

Carl A. Hatch, chairman for the committee

Report of the Joint Chiefs of Staff Evaluation Board

In compliance with a directive from the Joint Chiefs of Staff dated 27 February 1946, the Evaluation Board presents the following preliminary report of the atomic bomb test *A* held at Bikini Atoll on 1 July 1946. This report covers general observations only. Detailed evaluation must await full collection and analysis of data from observers and instruments and will be reported at a later date.

The members of the board inspected target ships the day before the test, witnessed the explosion from an airplane 20 miles distant, and then approached to within nine miles of the atoll for a brief view. On the following day, as soon as safety clearance had been received, the members flew to Bikini and began their examination of ship damage. Many photographs have been studied, and military and scientific specialists interviewed, in an attempt to obtain an over-all understanding of test results prior to the compilation of all the data.

From its previous study of the plans for the test, and from its observations in the Bikini area, the board considers that the test was well conceived and executed by the services in close cooperation with a large civilian staff. It is satisfied that the conditions of the test were well chosen and that the highest skill and ingenuity have been used to obtain a maximum amount of data in an unbiased, scientific manner. It believes that the commander, staff, and personnel of Task Force One deserve high commendation for their excellent performance and their notably co-operative spirit.

Effective precautions appear to have been taken to safeguard personnel against radioactivity and associated dangers.

The board's present information is that the bomb exploded, with an intensity which approached the best of the three previous atomic bombs, over a point 1,500 to 2,000 feet westerly of the assigned target, and at approximately the planned altitude.

The target array in no sense represented an actual naval disposition, but was designed to obtain the maximum data from a single explosion. The most important effects produced by the bomb are the following:

(*a*). A destroyer and two transports sank promptly and another destroyer capsized. It later sank, and the Japanese cruiser Sakawa sank the following day. The superstructure of the submarine Skate was so badly damaged as to make it unsafe to submerge the vessel. The light carrier Independence was badly wrecked by the explosion, gutted by fire, and further damaged by internal explosions of low order, including those of torpedoes. All the afore-mentioned vessels were within one half mile of the explosion point.

(*b*). Numerous fires were started on other ships, including one on a ship two miles distant, which was apparently due to some unusual circumstance, since the other fires were much closer. Here it should be remembered that the target ship decks carried a great variety of test material not ordinarily exposed on the decks of naval vessels.

(*c*). The only major combatant ships within one half mile of the explosion were the battleships Nevada and Arkansas and the heavy cruiser Pensacola. The blast struck these from the after quarter. Apparently little damage was done to their hulls or their main turrets but their superstructures were badly wrecked. These ships were unquestionably put out of action and would, along with many others within three quarters of a mile, have required extensive repairs at a principal naval base.

(*d*). Other ships in the target array suffered damage in varying degree, depending on position and type of ship, but there was relatively little damage at distances greater than three quarters of a mile.

(*e*). The primary material effects noted were due to blast; buckling of decks and bulkheads, and destruction or deformation of lightly constructed exposed objects, including stacks, masts, and antennas. Secondary effects were due to fire, and it is noteworthy that Army Quartermaster stores and miscellaneous equipment placed on the decks for the test proved more vulnerable than normal naval deck gear. It should be pointed out that since the targets carried no personnel the fires were uncontrolled and undoubtedly there was more damage than there would have been under battle conditions. Singularly, although considerable amounts of explosive ordnance were exposed on decks and in gun turrets, there is no indication on ships which remained afloat that any of this material was exploded by direct action of the atomic bomb. Fire fighting ships entered the target area as soon as they could obtain radiological security permission and subdued a number of fires. The speed and efficiency with which these ships acted preserved for later examination a great deal of evidence of bomb action which might otherwise have been lost.

(*f*). Examination of the flash burn effects produced by the initial radiation from the explosion indicates that casualties would have been high among exposed personnel. However, it is the opinion of the board that persons sheltered within the hull of a ship or even on deck in the shadow of radiation from the bomb would not have been immediately incapacitated by burns alone, whatever might have been the subsequent radiological effects.

(*g*). Within the area of extensive blast damage to ship superstructures there is evidence that personnel within the ships would have been exposed to a lethal dosage of radiological effects.

Personnel casualties due to the blast would no doubt have been high for these in exposed positions on vessels within a half mile of the target center. Beyond this any discussion of the blast effect upon personnel will have to await the detailed reports of medical specialists.

In general no significant unexpected phenomena occurred, although the test was designed to cope with considerable variation from predictions. There was no large water wave formed. The radioactive residue dissipated in the manner expected. No damage occurred on Bikini Island, about three miles from the explosion center.

From what it has seen and from what it has ascertained from data now available, the board is able to make certain general observations:

(*a*). The atomic bomb dropped at Bikini damaged more ships than have ever before been damaged by a single explosion.

(*b*). The test has provided adequate data of a sort necessary for the redesign of naval vessels to minimize damage to superstructures and deck personnel from this type of bomb. Because of the nature of the first test (air burst) little information has been obtained on hull effects. Damage to ships hulls will be studied specifically in the second test when a bomb will be exploded under water.

(*c*). A vast amount of data which will prove invaluable throughout scientific and engineering fields has been made available by this test. Once more the importance of large-scale research has been dramatically demonstrated. There can be no question that the effort and expense involved in this test has been amply justified both by the information secured and by greatly narrowing the range of speculation and argument. Moreover, it is clear to the board that only by further large scale research and development can the United States retain its present position of scientific leadership. This must be done in the interests of national safety.

The board desires to say that it has had the fullest co-operation of the Task Force commander, and that every opportunity has been afforded it in carrying out its mission. The members of the board have had access to all data thus far accumulated and have had every facility for personally inspecting the results of the test.

Karl T. Compton, chairman

Statistical Methods in Quality Control

XI. Statistical Tests of Significant Differences

INVARIABLY WE HAVE a limited sequence or set of observed values for each condition of interest, and inferentially some information regarding the parent universe, that is, the underlying distributive pattern that might appear with indefinitely repeated observation. It has been demonstrated, however, that even controlled processes and procedures do not provide identical repetitive results, due to a large number of small unidentifiable causes here referred to as chance causes. Such controlled pattern of variability follows some statistical law of distribution, as illustrated by $f(X)$ in Figure 1. An inference drawn from a finite sample of observations is a prediction of what would be found by indefinite repetition, and involves a degree of confidence, qualified by the chance or sampling error present. But if conditions are not controlled or constant, that is, assignable or identifiable causes of inconsistence are present, inferences based upon statistical laws lose their validity. Such control will be assumed to exist in the following discussion.

Statistical control of repeated operations has been discussed in previous articles of this series. Another problem of common occurrence is the statistical interpretation of limited experimental tests. These tests usually are designed to judge whether or not two comparative conditions provide an actual difference in some quality characteristic.

SAMPLE STATISTICS

It will be recalled that the relevant statistical information in a homogeneous set of n measurements usually can be summarized by:

(*a*). An average or mean ($\bar{X}$), as a location or center of gravity statistic.
(*b*). A standard deviation (σ).

a measure of dispersion about the average. The latter is the root-mean-square of the deviations of individual values from the group average,[1] defined and calculated for a sample of n values as follows:

$$\sigma = \sqrt{\frac{\Sigma_i(X_i - \bar{X})^2}{n}} = \frac{1}{n}\sqrt{n\Sigma_i X_i^2 - (\Sigma_i X_i)^2}$$

where ΣX is the sum of the individual values, and ΣX^2 is the sum of their squares. The corresponding statistical characteristics of the parent universe or long-run distribution of individuals, will be indicated herein by primes, as $\bar{X}'$ and σ'.

SIGNIFICANT LIMITS FOR THE SINGLE SAMPLE MEAN

Most practical to project is the chance variability of the means ($\bar{X}$) for repeated samples of size n. Suppose that conditions provide a universe of individuals distributed as function $f(X)$ in Figure 1, with standard deviation σ' about a universe mean $\bar{X}'$. A first sample under such conditions might have mean $\bar{X}_1$, a second same $\bar{X}_2$, and so on, all differing by chance or sampling error.[2] These, in the long run, would be distributed as function $f(\bar{X})$ in Figure 1 about the universe mean $\bar{X}'$, with a standard deviation of means, $(\sigma'/\sqrt{n})$.

Further in such case of means, we well can establish upper and lower symmetrical limits $\bar{X}_L$, beyond which an observed mean for given sample size rarely would fall by chance alone, if the visualized universe existed. These are shown in Figure 1, where the sum P of the selected "tail area" probabilities, P_1 and P_2, represents the risk of a mean falling outside the given range by sampling alone. Such limits usually are expressed as distances from average expectation $\bar{X}'$, in terms of standard deviation units T, as $\bar{X}' \pm T(\sigma'/\sqrt{n})$. In practice we rarely know the exact distributive form of universe at hand, and cannot project precise probabilities and limits for the various statistics used. However, we do know that only a small limiting proportion of observed sample values can fall outside limits calculated with a fairly large T, say of the order of 2.5 or 3.0*. Usually, however, information regarding the standard deviation must be obtained from the sample. With

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Personnel of the AIEE subcommittee on educational activities: J. Manuele, H. F. Dodge, A. I. Peterson, and R. E. Wareham.

* Although statisticians often assume some theoretical distribution law and deduce limits based upon refined standards for P, say 0.001, engineers often use a more rational approach with $T = 3.0$. With the theoretical normal curve model of error, $T = 3.29$ is associated with $P = 0.001$, and $T = 2.58$ with $P = 0.01$.

reasonably general confidence we then, in place of T, use a corresponding function known as "student's t," for small samples. Limits for means then would be calculated as

$$\bar{X}_L = \bar{X}' \pm t(\sigma/\sqrt{n-1})$$

where σ is observed in the sample. The values of t are numerically larger than T in comparable cases, to allow for the sampling error now present in the sample values of σ. Tables of t are generally available in texts, for given levels of P, and for various degrees of freedom n', here equal to one less than the sample size, for instance, $n'=n-1$. An extract from such table, for the case of $P=0.01$, is as follows:

Degree of Freedom n'	Values of Student's t
3	5.84
4	4.60
8	3.36
30	2.75
Infinite	2.58

With an "allowable" t from the table, we project our limits in the case where some standard of expected value $\bar{X}'$ is assumed; then observe whether or not our observed mean conforms to the sampling error range defined.

A more direct approach with the same end calculates the number of standard deviation units, T_0 or t_0, in the observed difference between sample mean $\bar{X}$ and expected mean $\bar{X}'$; then compares this with an "allowable" T or t, corresponding to a chosen level of significance or risk P. The calculations would be as follows:

$$T_0 = (\bar{X} - \bar{X}')/(\sigma'/\sqrt{n})$$

or

$$t_0 = (\bar{X} - \bar{X}')/(\sigma/\sqrt{n-1})$$

Assume that somehow, by exhaustive and controlled repetition, a lot of metal filament has had its true mean strength substantially identified as $\bar{X}'=14.00$ ounces. It is suspected that an added given treatment will increase the strength. A random selection from the same lot is treated and tested, providing say only five readings with sample $\bar{X}=15.70$ ounces and $\sigma=0.75$ ounce. As a conventional working hypothesis, we approach our inference with the view that no change should result, that is, we use a null-hypothesis. Now assume that the level of risk chosen is $P=0.01$, the afore-mentioned table giving an "allowable" value of $t=4.60$, for a sample with degrees of freedom $n'=5-1=4$. The sample value calculated is

$$t_0 = (15.70-14.00)/(0.75/\sqrt{5-1}) = +4.53$$

Since the observed t_0 is numerically less than the allowable t, it has been conventional to consider that the observed difference could have arisen by chance alone. We are not inclined, therefore, to reject the hypothesis. But we are by no means in a position to consider the null-hypothesis proved, a point made clearer in the following. The limitations of single small samples are obvious. Further, alternative values just inside and outside any arbitrary extreme limit are not greatly different logically, since both are sufficiently extreme in the same direction, and still leave some doubt as to a conclusive chance explanation. The use of a larger sample would have narrowed the zone of doubt to be differentiated in original units measured.

SIGNIFICANT DIFFERENCES BETWEEN TWO MEANS

Another common case is a comparison of the means of two samples, approached by a similar working hypothesis. Two samples are tested, the second possibly differing because of the test condition changed for comparison (for the added treatment in the foregoing problem). We now have two sample means, $\bar{X}_1$ and $\bar{X}_2$, and two standard deviations, σ_1 and σ_2. The null-hypothesis is that both have the same true universe mean, that $\bar{X}_1' - \bar{X}_2' = 0$. Subject to a test not discussed in this article, it is assumed that both have the same true standard deviation, and that the question to be answered lies only in some possible difference in the means.

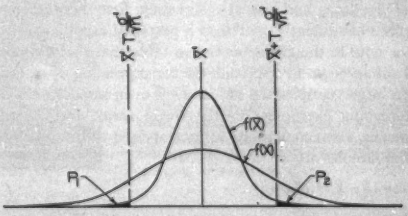

Figure 1

We then calculate the observed value of t as follows:

$$t_0 = (\bar{X}_1 - \bar{X}_2)/\sigma_{\bar{X}_1 - \bar{X}_2}$$

where the denominator represents the standard deviation of the difference in two means, given from the sample

$$\sigma_{\bar{X}_1 - \bar{X}_2} = \sqrt{\left(\frac{n_1\sigma_1^2 + n_2\sigma_2^2}{n_1+n_2-2}\right)\left(\frac{n_1+n_2}{n_1 n_2}\right)}$$

The allowable t again is found in the student's t tables, but for degrees of freedom now equal to (n_1+n_2-2). The observed t_0 is compared with the "allowable" t as before.

For example, assume two test samples of five each

taken at random from the same lot of material, one to be tested for tensile strength after an added treatment, the other tested untreated. The sample results were

$\bar{X}_1 = 14.15$
$\bar{X}_2 = 13.05$
$\sigma_1 = 0.82$
$\sigma_2 = 0.65$

The "allowable" value of t; for $(5+5-2)=8$ degrees of freedom and $P=0.01$, is $t=\pm 3.36$. The observed value of t calculations is

$$\sigma_{\bar{X}_1-\bar{X}_2} = \sqrt{\frac{5(0.672)+5(0.422)}{5+5-2}\left(\frac{5+5}{(5)(5)}\right)}$$

$$= 0.523$$

$$t_0 = \frac{14.15-13.05}{0.523} = 2.50$$

The observed value 2.50 is well within the "allowed" value 3.36, and the apparent difference is considered possibly due to chance. The null-hypothesis cannot yet be considered untenable.

LARGE SAMPLES

When sample sizes are "large," by definition greater than 30, we generally neglect the adjustments for degrees of freedom, and use the T values first mentioned in place of student's t. This is a practical expedient, since we note in the afore-mentioned table that the allowable t values begin to approach the corresponding T values.* In larger samples the difference is even smaller. In the foregoing examples, for the single mean and for two means, the calculations using standard deviations from the samples are

$$T_0 = (\bar{X} - \bar{X}')/(\sigma/\sqrt{n})$$

or

$$T_0 = (\bar{X}_1 - \bar{X}_2)/\sigma_{\bar{X}_1-\bar{X}_2}$$

where

$$\sigma_{\bar{X}_1-\bar{X}_2} = \sqrt{\left(\frac{n_1\sigma_1^2+n_2\sigma_2^2}{n_1+n_2}\right)\left(\frac{n_1+n_2}{n_1n_2}\right)}$$

The allowable T in either case might be taken as 2.58, for $P=0.01$, or can be selected for other P levels from tables of the normal distribution.*

LIMITATIONS

The foregoing techniques, illustrated for means only, generally have been called tests of significance. They have been useful disciplines in experimental development, but also have been misused through superficial generalization and enthusiasm.

We have demonstrated limits for sampling error based upon some level of risk P, for judging the "significance" of a departure from a reference condition. This P is called an "error of the first kind." It is a risk of rejecting the no-change hypothesis by chance, when actually true, that is, of concluding in error that a change from the reference condition has occurred.

However, it is critically important to note again that the alternative appearance of an observed result within such limits cannot be taken as equally valid evidence that no true change has occurred. Figure 2 reconstructs the sampling distribution of means of Figure 1, around the reference value $\bar{X}'$. If, conceivably, the true mean

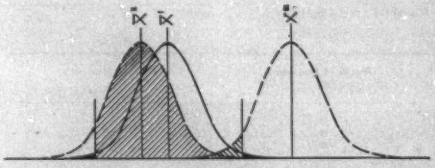

Figure 2

after treatment actually had changed by a relatively slight amount, say to position $\bar{X}''$, the shaded portion of a distribution shown at this position indicates the large chance that a sample mean would have of falling within the originally projected limits in any circumstances. Further, this is true in varying degree for many other possibly true means within a linear region out to $\bar{X}'''$ on either side, where the shading has dropped to a low value. We now can appreciate by illustration that there can be a very real risk of an "error of the second kind"; that of accepting a null-hypothesis when it is false.

There are many difficulties in constructing simple tests that reflect both types of allowable error, and their discussion is far beyond the scope of this article. However, when only a small sample is available, the foregoing technique is of some help, in that we avoid conclusions masked by a range of sampling error inherent to the operation. A nonsignificant difference holds the null-hypothesis in suspense as "not disproved," rather than "proved." Repetitions of such test of course will provide further information, particularly if the relative frequencies with which results fall below, within, and above their limit range interval are compared with expected relative frequencies.

It is evident, of course, that even with the simple methods, the range of uncertainty can be reduced numerically by employing a larger sample.

REFERENCES

1. Statistical Methods in Quality Control—II. *Electrical Engineering*, volume 64, July 1945, pages 249–50.

2. Statistical Methods in Quality Control—V. *Electrical Engineering*, volume 64, October 1945, pages 363–4.

* The normal distribution integral, or areas from the mean to various numbers of standard deviations, is available in practically all statistics textbooks. It can be noted that the T values of the normal distribution correspond to student t values for infinite degrees of freedom.

INSTITUTE ACTIVITIES

Industrial Subjects Featured on Great Lakes Meeting Program

The Great Lakes District meeting to be held in Indianapolis, Ind., October 9–11 is sponsored jointly by the Fort Wayne and Central Indiana Sections. Meeting headquarters will be in the Claypool Hotel. As this District covers a large industrial area, a considerable portion of the program deals with industrial problems. Special attention is called to the general meeting Thursday afternoon conducted by the committee on planning and co-ordination. This conference will be a continuation of similar meetings held at the winter convention, summer convention, and at several District meetings, and everyone is urged to attend.

Harding Street plant of Indianapolis Power and Light Company with construction work for fourth unit shown at right

TECHNICAL SESSIONS

During the three days of the meeting, seven technical sessions and conferences will be held on the following subjects: electric machinery, electronics, power transmission and distribution, industrial power applications, communications, industrial control, and basic sciences.

INSPECTION TRIPS

On Friday afternoon inspection trips will be made to the following power stations and industries:

Marmon Herrington Company in Indianapolis is long established in the automotive industry as a builder of special mobile transportation equipment and lately has started the manufacture of all-electric-drive trolley coaches of modern design.

The Esterline-Angus Company, Inc., in Speedway City has long been recognized throughout the industry in the development and manufacture of quality recording instruments with universal applications to many problems.

Eli Lilly and Company, manufacturer of medicinal products, has its home office in Indianapolis. In its plant may be seen the application of science to the production of medicine. Perhaps no industrial plant requires a greater diversity of equipment or embraces in its personnel a wider range of technical knowledge and skill.

Public Service Company of Indiana, Inc., has at its Lenore substation, Indianapolis, an interesting central power dispatching station for its entire system with associated carrier-current telemetering, carrier-frequency control, and relaying.

Indianapolis Power and Light Company's Harding Street station, is the main source of Indianapolis power supply. Its present rated capacity is 111,000 kw, provided by two units installed in 1931 and a third in 1941–42. A fourth unit similar to the third, with a 37,500-kw turbogenerator and a steam generator capable of delivering 400,000 pounds per hour at 875 pounds pressure and 900 degrees Fahrenheit temperature, is under installation. Exhibited at this plant is the first Curtis turbogenerator to go into commercial operation, at Newport, R. I., in 1903.

Large electric stripping shovel at Ayrshire Collieries Corporation, to which an inspection trip will be made during the Great Lakes District meeting

EXHIBITS

Concurrently with the meeting a few appropriate exhibits will be established on the mezzanine floor of the Claypool Hotel. For information on exhibit space refer to J. L. Wright, Jr., 4241 Melbourne Road, Indianapolis.

ENTERTAINMENT

A banquet will be held at 6:30 p.m., Thursday, October 10, in the Riley Room of the Claypool Hotel. An entertainment program for the women also will be provided.

HOTEL ACCOMMODATIONS

The hotel and registration committee is handling reservations for the Claypool Hotel, meeting headquarters. Reservations should be made by addressing S. C. Leibing, chairman, 301 Traction Terminal Building, Indianapolis 4, Ind. The Clay-

pool Hotel has reserved 200 rooms. The rates are:

Single bed—$2.75, $3, and $3.50.
Double bed—$5.50.
Twin beds—$6, $7.15, and $7.70.

Those desiring room reservations should write promptly, indicating the rate of room desired and the number of occupants in one party. Due to present-day conditions those desiring rooms are urged to apply immediately. Confirmation will be sent by postcard, if desired.

ADVANCE REGISTRATION

Please register in advance. This will save time at the registration desk. A registration fee of $2 will be charged nonmembers except Student Members and the immediate families of members.

COMMITTEE

F. H. Fleischer and S. C. Leibing are cochairmen of the meeting committee. Subcommittee chairmen are:

C. M. Summers, *meetings and papers;* S. C. Leibing, *entertainment, hotels, and registration;* J. L. Wright, Jr., and S. A. Zimmermann, cochairmen, *publicity and exhibits;* C. E. Chatfield, *inspection trips;* E. R. Linke, *finance;* S. J. Winge, *student activities.*

Technical Program and Meeting Features

● **PAMPHLET reproductions of authors' manuscripts of the numbered papers listed in the program may be obtained as noted in the following paragraphs.**

● **ABSTRACTS of numbered papers appear on page 471 of this issue.**

● **PRICES and instruction for procuring advance copies of these papers will accompany the abstracts. Mail orders are advisable, particularly from out-of-town members, as an adequate supply of each paper at the meeting cannot be assured. Only numbered papers will be available in pamphlet form.**

Wednesday, October 9

8:30 a.m. Registration

9:45 a.m. Opening session

S. C. Leibing, presiding

Welcome: The Honorable **Robert H. Tyndall,** Mayor of Indianapolis

Announcements

10:00 a.m. Electric Machinery

M. S. Oldacre, presiding

46-202. Asynchronous and Single-Phase Operation of Synchronous Machines. **A. W. Rankin,** General Electric Company

DP.* Fractional Horsepower Motors for Operation on Thyratrons. **W. R. Goss, F. T. Carlson,** General Electric Company

DP.* Properties of Magnet Wire. **H. A. Smith,** General Electric Company

CP.† New NEMA Fractional Horsepower Motor Standards: Their Effect on Refrigeration and Pump Application. **C. P. Potter,** Wagner Electric Corporation

2:00 p.m. Electronics

O. W. Livingston, presiding

DP.* Electronics in Measurements. **R. J. Kryter,** Esterline-Angus Company

46-203. Frequency Performance of Thyratrons. **H. H. Wittenberg,** RCA Manufacturing Company

DP.* Microwave Magnetrons. **F. F. Reike,** Purdue University

CP.† Electron and Ion Beam Instruments. **G. W. Dunlap,** General Electric Company

2:00 p.m. Power Transmission and Distribution

F. V. Smith, presiding

DP.* Simplicity in Transformer Protection. **E. T. B. Gross,** Illinois Institute of Technology

DP.* Rural Electrification in Iowa. **C. M. Stanley,** Stanley Engineering Company

DP.* Experience With Single-Pole Relaying and Reclosing on a Modern 132-Kv System. **J. J. Trainor, C. E. Parks,** Public Service Company of Indiana

DP.* Calculation of Power System Losses by Formula Using Constants Determined by the Network Analyzer. **J. B. Ward,** Purdue University

CP.† Trends in Rural-Line Sectionalizing. **R. F. Quinn,** General Electric Company

Thursday, October 10

9:30 a.m. Industrial Power Applications

L. A. Umansky, presiding

CP.† Multiple Generator for Paper Machines. **G. E. Plaisted,** General Electric Company

CP.† Lightning Protection for Industrial Plants. **E. W. Beck, J. Z. Linsenmeyer,** Westinghouse Electric Corporation

CP.† Automatic Contouring Control. **J. M. Morgan,** General Electric Company

CP.† Demonstration of Industrial Distribution System. **H. G. Barnett,** Westinghouse Electric Corporation

9:30 a.m. Communications

J. J. Pilliod, presiding

DP.* Manufacturing Problems of Air-Borne Transmitter Equipment. **J. A. Green,** Collins Radio Company

DP.* Phenomenon of Microwaves (demonstration). **H. R. Gruelle,** Indiana Bell Telephone Company

46-204 ACO.** Analysis of Four-Terminal Networks Containing Vacuum Tubes. **W. R. Abbott,** Iowa State College

DP.* Mobile Radiotelephone Service. **J. G. Harden,** Indiana Bell Telephone Company

46-205. A Multichannel Microwave Radio Relay System. **H. S. Black, J. W. Beyer, T. J. Grieser, F. A. Polkinghorn,** Bell Telephone Laboratories, Inc.

2:00 p.m. Discussion on the Organization of the Engineering Profession

T. G. LeClair, presiding

The conference will be devoted to discussion of activities of the committee on planning and co-ordination, including organization of the engineering profession as a whole and discussion of the four proposed plans of organization. Following the discussion the members will be given an opportunity to record their opinions of the plans for the guidance of the professional activities subcommittee in their further consideration of the organization problem.

6:30 p.m. Banquet

T. G. LeClair, presiding

Address: Nature and Implications of Atomic Energy. **Doctor Frank H. Spedding**

Doctor Spedding is a member of the Manhattan District Declassification Committee. This is the national committee that has been set up to recommend what scientific information obtained during the war in connection with atomic research can be released at this time in order to aid in the progress of scientific development. Doctor Spedding was flown to and from the Pacific in order to witness the Bikini tests.

Friday, October 11

9:30 a.m. Industrial Control

R. W. Jones, presiding

CP.† Trends in Co-ordinated Control. **G. A. Moffett,** General Electric Company

DP.* Control of Slip-Ring Motors by Means of Unbalanced Primary Voltages. **N. L. Schmitz,** Cutler-Hammer, Inc.

DP.* Problems in Design of A-C Magnets and Solenoids. **L. T. Rader,** Illinois Institute of Technology

9:30 a.m. Basic Sciences

K. W. Miller, presiding

CP.† The Electronic Numerical Integrator and Computor. **T. K. Sharpless,** University of Pennsylvania

CP.† Radioactive Isotopes and Their Application. **G. Freidlander,** General Electric Company

DP.* Latest Developments in High-Energy Physics. **Karl Lark-Horovitz,** Purdue University

DP.* Solar Electron Radiation and Its Effect on Power Transmission and Communications. **J. T. Wilson,** Allis-Chalmers Manufacturing Company

12:30 p.m. Luncheon and Meeting of Great Lakes District executive committee

1:30 p.m. Inspection Trips

*DP: District paper; no advance copies are available; not intended for publication in *Transactions.*

†CP: Conference paper; no advance copies are available; not intended for publication in *Transactions.*

**ACO: Advance copies only available; not intended for publication in *Transactions.*

AIEE Officers to Be Nominated for 1947 Election

For the nomination of officers to be voted upon in the spring of 1947, the AIEE nominating committee will meet in New York, N. Y., in January 1947. The officers to be elected are: a president, a treasurer, three directors, and five vice-presidents, one from each of the even-numbered geographical Districts. Fellows only are eligible for the office of president, and Members and Fellows for the offices of vice-president, director, and treasurer.

To guide this committee in performing its constituted task, suggestions from the membership are, of course, highly desirable. To be available for the consideration of the committee, all such suggestions must be received by the secretary of the committee at Institute headquarters, not later than December 15, 1946.

In accordance with the provisions in the constitution and bylaws, as amended during 1935 and quoted in the following paragraphs, actions relating to the organization of the nominating committee are now under way.

Constitution

28. There shall be constituted each year a nominating committee consisting of one representative of each geographical District, elected by its executive committee, and other members chosen by and from the board of directors not exceeding in number the number of geographical Districts; all to be selected when and as provided in the bylaws. The secretary of the Institute shall be the secretary of the nominating committee, without voting power.

29. The executive committee of each geographical District shall act as a nominating committee of the candidate for election as vice-president of that District, or for filling a vacancy in such office for an unexpired term, whenever a vacancy occurs.

30. The nominating committee shall receive such suggestions and proposals as any member or group of members may desire to offer, such suggestions being sent to the secretary of the committee.

The nominating committee shall name on or before January 31 of each year, one or more candidates for president, treasurer, and the proper number of directors, and shall include in its ticket such candidates for vice-presidents as have been named by the nominating committees of the respective geographical Districts, if received by the nominating committee when and as provided in the bylaws; otherwise the nominating committee shall nominate one or more candidates for vice-president(s) from the District(s) concerned.

Bylaws

Sec. 22. During September of each year, the secretary of the nominating committee shall notify the chairman of the executive committee of each geographical District that by December 15 of that year the executive committee of each district must select a member of that District to serve as a member of the nominating committee, and shall by December 15, notify the secretary of the nominating committee of the name of the members elected.

During September of each year, the secretary of the nominating committee shall notify the chairman of the executive committee of each geographical District in which there is or will be during the year a vacancy in the office of vice-president, that by December 15 of that year a nomination for a vice-president from that District, made by the District executive committee, must be in the hands of the secretary of the nominating committee.

Between October 1 and December 15 of each year, the board of directors shall choose 5 of its members to serve on the nominating committee and shall notify the secretary of that committee of the names so selected and shall also notify the 5 members selected.

The secretary of the nominating committee shall give the 15 members so selected not less than 10 days' notice of the first meeting of the committee, which shall be held not later than January 31. At this meeting, the committee shall elect a chairman and shall proceed to make up a ticket of nominees for the offices to be filled at the next election. All suggestions to be considered by the nominating committee must be received by the secretary of the committee by December 15. The nominations as made by the nominating committee shall be published in the March issue of *Electrical Engineering* (Journal of AIEE), or otherwise mailed to the Institute membership not later than the first week in March.

INDEPENDENT NOMINATIONS

Independent nominations may be made in accordance with provisions in article VI, section 31, of the constitution and section 23 of the bylaws, which are quoted below:

Constitution

31. Independent nominations may be made by a petition of twenty-five (25) or more members sent to the secretary when and as provided in the bylaws; such petitions for the nomination of vice-presidents shall be signed only by members within the District concerned.

Bylaws

Sec. 23. Petitions proposing the names of candidates as independent nominations for the various offices to be filled at the ensuing election, in accordance with article VI, section 31 (constitution), must be received by the secretary of the nominating committee not later than March 25 of each year, to be placed before that committee for the inclusion in the ballot of such candidates as are eligible.

On the ballot prepared by the nominating committee in accordance with article VI of the constitution and sent by the secretary to all qualified voters during the first week in April of each year, the names of the candidates shall be grouped alphabetically under the name of the office for which each is a candidate.

(*Signed*) H. H. Henline,
Secretary

Winter Meeting Committees Appointed for 1947 and 1948

Announcement of the members of the winter meeting committees for 1947 and 1948 has been made by AIEE President J. E. Housley. The committee for the 1947 winter meeting, which will be held in New York, N. Y., as is customary, will be:

C. S. Purnell, *chairman;* W. J. Barrett; O. E. Buckley; P. C. Cromwell; M. D. Hooven, R. A. Jones; A. E. Knowlton; J. H. Pilkington.

The committee for the 1948 winter meeting to be held in Pittsburgh, Pa., is:

C. A. Powel, *chairman;* C. T. Sinclair, *vice-chairman;* L. N. Grier, *secretary-treasurer;* H. S. Fitch; Paul Frederick; J. R. MacGregor; and A. C. Monteith.

Lamme Medal Nominations Due December 1, 1946

Attention is called again to the opportunity open to any Institute member to submit nominations for the 1946 AIEE Lamme Medal. All nominations must be received not later than December 1. For further particulars see *Electrical Engineering*, July 1946, page 330.

The 1945 medal was awarded to David C. Prince, vice-president, general engineering and consulting laboratory, General Electric Company, Schenectady, N. Y. An account of the presentation of the medal to him was published in the October 1946 issue of *Electrical Engineering*, page 435.

Future AIEE Meetings

Great Lakes District Meeting
Indianapolis, Ind., October 9–11, 1946

Winter Meeting
New York, N. Y., January 27–31, 1947

North Eastern District Meeting
Worcester, Mass., April 23–25, 1947

Summer Meeting
Montreal, Quebec, Canada, June 9-13, 1947

Additional Member for Life. The name of Claude A. Jagger (A '11) engineer of the control engineering division, General Electric Company, Schenectady, N. Y., was omitted from the list of new members for life published in the July 1946 issue of *Electrical Engineering*, page 352. Mr. Jagger's status as an AIEE member for life became effective November 1, 1945.

Lightning Handbook in Preparation. The lightning and insulator subcommittee of the AIEE committee on power transmission and distribution has announced that volume II of the "AIEE Lightning Reference Book" is nearing completion. It is expected that the second volume will be the same size as the first—about 1,500 pages. Besides including approximately 200 articles, the book will contain an index of more than 200 additional articles for reference only. The book will be for sale on a nonprofit basis, and the subcommittee is endeavoring to insure a supply which will meet the expected large demand.

ABSTRACTS• • • •

TECHNICAL PAPERS previewed in this section will be presented at the AIEE Great Lakes District meeting, Indianapolis, Ind., October 9–11, 1946, and will be distributed in advance pamphlet form as soon as they become available. Copies may be obtained by mail from the AIEE order department, 33 West 39th Street, New York 18, N. Y., at prices indicated with the abstract; or at five cents less per copy if purchased at AIEE headquarters or at the meeting registration desk.

Mail orders will be filled AS PAMPHLETS BECOME AVAILABLE

Communication

46-205—A Multichannel Microwave Radio Relay System; *H. S. Black* (*F* '41), *J. W. Beyer* (*M* '36), *T. J. Grieser, F. A. Polkinghorn* (*M* '39). *25 cents.* An eight-channel microwave relay system is described. Known as AN/TRC-6, the system uses radio frequencies approaching 5,000 megacycles. At these frequencies, there is a complete absence of static and most man-made interference. The waves are concentrated into a sharp beam and do not travel along the earth much beyond seeing distances. Other systems using the same frequencies can be operated in the near vicinity. The transmitter power is only

1/4,000,000 as great as would be required with nondirectional antennas. Short pulses of microwave power carry the intelligence of the messages utilizing "pulse position modulation" to modulate the pulses and "time division" to multiplex the channels. The eight-message circuits which each system provides are high grade telephone circuits and can be used for signaling, dialing, facsimile, picture transmission, or multichannel voice frequency telegraph. Two-way voice transmission over radio links totaling 1,600 miles and one way over 3,200 miles have been accomplished successfully in demonstrations.

Electric Machinery

46-202—Asynchronous and Single-Phase Operation of Synchronous Machines; *A. W. Rankin (M '45). 30 cents.* The object of this paper is to present an analysis of the asynchronous and single-phase operation of synchronous machines. The analysis of such operation is quite involved, and the number of pertinent variables is so large that the physical aspects of the problem tend to become completely submerged in the mathematical manipulations involved. In the subject paper the analysis is made by means of equivalent circuits, and the various torques and currents of the synchronous machines are all presented in terms of the currents and voltages of these equivalent circuits. To illustrate the practicability of the methods, a numerical example is given comparing the asynchronous and single-phase operating characteristics of synchronous machines with complete and incomplete end rings on the damper windings. This example presents the torque curves, the stator and rotor currents, and the current distribution in the leading and trailing bars of the damper winding.

Electronics

46-203—Frequency Performance of Thyratons; *H. H. Wittenberg (A '46). 20 cents.* The frequency performance of small thyratrons is investigated by supplying anode voltage from a variable-frequency electronic generator of 1,400-watts output capacity. At high audio frequencies there is a departure from the 60-cycle-per-second performance; the grid control characteristic resolves itself into two characteristics: a starting characteristic and an extinguishing characteristic. The starting characteristic is shown to be a function of grid–anode capacitance and grid resistance. The extinguishing characteristic is determined by deionization effects and so is a function of frequency, grid resistance, anode current, tube geometry, and gas pressure.

46-204-ACO—Analysis of Four-Terminal Networks Containing Vacuum Tubes; *W. R. Abbott (A '40). 15 cents.* A method is given for handling as a class four-terminal networks containing vacuum tubes. In linear passive four-terminal networks, three independent functions of frequency are sufficient to describe the behavior of the network at its input and output terminals. If the network contains class *A* operated vacuum tubes, the network remains linear; but four independent functions of frequency are necessary to describe its behavior. In this paper three sets of four independent functions are discussed, and an example is worked out in which all three are used.

PERSONAL ••••

Robert Hamilton Barclay (A '14, M '18, F '28) chief electrical engineer, electrical engineering department, J. G. White Engineering Corporation, New York, N. Y., has been appointed 1946–47 chairman of the AIEE board of examiners of which he has been a member since 1943. Born in St. Louis, Mo., August 10, 1887, Mr. Barclay attended Washington University. After holding various positions with the Laclede Power Company of St. Louis (Mo.), the Hartford (Conn.) Electric Light and Power Company, and at the World's Fair in St. Louis in 1904, he became associated with the Bell Telephone Company of Missouri, St. Louis, and the Missouri and Kansas Telephone Company, Kansas City, Mo., in 1908 as telephone engineer and superintendent of buildings and power plants as well as chief draftsman. In 1912 he entered the employ of the Kansas City (Mo.) Terminal Railway Company as assistant electrical engineer, and in 1915 he joined the Brooklyn–Manhattan Transit Corporation, Brooklyn, N. Y., in the same capacity. From 1917 to 1922 Mr. Barclay was employed as chief electrical engineer for The Foundation Company, New York, N. Y. While thus employed he was responsible for the electrical engineering and electrical construction of two large loading plants for the United States Government during World War I and also for the design and construction of several shipyards and approximately 40 vessels. Mr. Barclay became chief electrical engineer for Starrett and Van Vleck, Architects, New York, N. Y., in 1922, and in 1924 was appointed electrical engineer for the Stone and Webster Corporation, Boston, Mass. After three years as president of McClelland Barclay Art Products, Inc., New York, N. Y., he was appointed chief of the analysis and reports division, Federal Power Commission, National Power Survey, Washington, D. C., in 1934. He became regional director of the Commission in New York in 1936 with jurisdiction over the area embracing New England, New York, New Jersey, Pennsylvania, Delaware, Maryland, and the District of Columbia. In 1938 he was expert adviser to the Joint Committee on the Investigation of the Tennessee Valley Authority on matters relating to the design, construction, operation, and integration of the power generating facilities of the Tennessee Valley Authority. He joined the J. G. White Engineering Corporation in 1941. Mr. Barclay became a member of the Engineering Societies Library board in 1942 and and has been vice-chairman since 1944. Mr. Barclay is a member of the Radio Club of America, the Society of American Military Engineers, and The Engineers' Club of New York.

M. S. Oldacre (A '13, M '42) director of research, Utilities Research Commission, Commonwealth Edison Company, Chicago, Ill., has been appointed 1946–47 chairman of the AIEE committee on electric machinery of which he has been a member since 1939. He was born January 8, 1889, in Chicago, Ill., and was graduated in 1910 from Purdue University with a bachelor of science degree in electrical engineering. Following his graduation he was employed by the Commonwealth Edison Company as electrical mechanic and helper in the construction department and in 1912 was made testing engineer. He remained with the Commonwealth Edison Company until in 1918 he joined the United States Army to serve as second lieutenant during the first World War. In 1919 Mr. Oldacre entered the employ of the Westinghouse Electric and Manufacturing Corporation, South Philadelphia, Pa., as engineer in the stoker engineering department, and in 1920 he became stoker service engineer in charge of stoker service work in the Chicago, Ill., area. He was transferred to Minneapolis, Minn., in 1922 as sales engineer for the Westinghouse company and in 1923 returned to Chicago as engineer specialist on turbines, capacitors, and stokers. In 1926 he re-entered the employ of the Commonwealth Edison Company as engineer in the engineering department. He was advanced to the position of research engineer in 1935 and was made equipment and research engineer in 1937. In 1946 he was appointed to the re-

M. S. Oldacre

S. M. Dean

R. H. Barclay

J. G. Tarboux

C. W. Evans

M. J. Steinberg

H. W. Collins

search commission. Mr. Oldacre's Institute activities include past membership on the Standards and transfers committees.

Samuel Mills Dean (A '25, M '41, F '46) chief engineer of the system, Detroit (Mich.) Edison Company, has been appointed chairman of the AIEE committee on the Edison Medal for 1946–47. Born in Traverse City, Mich., July 15, 1891, he was graduated from Michigan State College in 1914 with a bachelor of science degree in electrical engineering. From 1914 until 1916 he was with the Michigan Miller's Mutual Fire Insurance Company, Lansing, after which he entered the test course of the General Electric Company, Schenectady, N. Y. He was transferred to the general office of the commercial department in 1918 and in 1919 became sales engineer in the Chicago, Ill., district office. In 1921 he was made assistant manager of the company's Detroit office. Joining the Detroit Edison Company in 1925, he held various engineering positions before his appointment as senior engineer in charge of the engineering division of the company in 1927. Mr. Dean became chief assistant superintendent of the electric system in 1930 and chief engineer of the system in 1943. In the latter position he has charge of all system engineering and of planning system design. He was 1940–41 secretary of the AIEE Detroit Section. He is a member of Tau Beta Pi and the Engineering Society of Detroit and has contributed a number of articles to technical publications.

Joseph Galluchat Tarboux (A '21, M '32, F '43) professor of electrical engineering, Cornell University, Ithaca, N. Y., has been appointed chairman of the AIEE committee on education for 1946–47. Professor Tarboux was born in Juiz de Fora, Minas Geraes, Brazil, August 15, 1898. He was graduated from Clemson Agricultural College in 1918 with bachelor of science degrees in electrical engineering and mechanical engineering, and from Cornell University he received the degrees of electrical engineer in 1922, master of electrical engineering in 1925, and doctor of philosophy in 1936. From 1919 to 1929 Professor Tarboux was instructor and assistant professor of electrical engineering, Cornell University. He joined the faculty of the University of Tennessee, Knoxville, in 1929, as professor in charge of the electrical engineering department, and held that position until his recent return (*EE, Aug-Sept '46, p 417*) to the faculty of Cornell University. Professor Tarboux is a member of the Knoxville Technical Society and the Knoxville Science Society, and has been an AIEE Student Branch counsellor since 1930. He is a member of Eta Kappa Nu, Tau Beta Pi, Phi Kappa Phi, and Sigma Xi, and is the author of several books.

Harold Wilson Collins (A '22, M '42) superintendent of the electrical system, The Detroit (Mich.) Edison Company, has been appointed 1946–47 chairman of the AIEE committee on protective devices of which he has been a member since 1931. Born December 23, 1895, in Owosso, Mich., Mr. Collins is a graduate of the University of Michigan, Ann Arbor, with a degree in electrical engineering (1918). After several months as an instructor in the University of Michigan's electrical engineering department, he began work for The Detroit Edison Company in 1919 in the operating department. His first duties were concerned with the testing of electric apparatus and underground cables. In 1926 he was appointed relay engineer in charge of system protection, and in 1928 he assumed additional responsibilities for the performance of other classes of equipment in order to maintain service continuity and standards. Mr. Collins became assistant to the superintendent of the electrical system in 1929 and project engineer in 1930. He was made superintendent of the electrical system in 1945.

Max Jacob Steinberg (A '24, M '32) division engineer, system engineering department, Consolidated Edison Company of New York (N. Y.), Inc., has been appointed 1946–47 chairman of the AIEE committee on power generation of which he has been a member since 1939. He was born in Russia, April 15, 1900, and received the bachelor of science degree in 1922 and the master of science degree in 1923 from Massachusetts Institute of Technology. He received the degree of bachelor of laws in 1928 from Brooklyn Law School. In 1920 and 1921 Mr. Steinberg was associated with the General Electric Company, West Lynn, Mass., and in 1923 he entered the employ of the Brooklyn (N. Y.) Edison Company to supervise the testing of generating equipment. He became engaged in general engineering in connection with system operating in 1929. Mr. Steinberg was appointed division engineer for the Consolidated Edison Company in 1937. He is a part-time lecturer at New York University and Brooklyn Polytechnic Institute. Mr. Steinberg, who is also a member of the American Society of Mechanical Engineers, is at present chairman of the joint AIEE–ASME Committee on a Recommended Specification for Prime-Mover Speed Governing. He is a member of the New York State Society of Professional Engineers.

Carl Wimmer Evans (A '36, M '40) editor, *Electrical South*, W. R. C. Smith Publishing Company, Atlanta, Ga., has been appointed 1946–47 chairman of the AIEE committee on domestic and commercial applications of which he has been a member since 1943. Mr. Evans was born November 23, 1905, in San Antonio, Tex. After attending the University of Texas, he became journeyman electrician for the San Antonio Public Service Company in 1928 and was named underground distribution engineer in 1929. In the latter position he had charge of the planning and design of the company's underground distribution system. In 1931 Mr. Evans was appointed industrial power sales engineer, and in 1933 commercial engineer in charge of the rate and statistical division. He resigned from this position in 1936 to join the staff of *Electrical South* as associate editor, becoming editor later that year. Mr. Evans served as secretary of the AIEE Georgia Section for 1941–44 and as chairman for 1945–46. He is a member of the Illuminating Engineering Society, the International Association of Electrical Inspectors, and the Georgia Engineering Society.

Titus George LeClair (A '24, M '29, F '40) staff engineer, Commonwealth Edi-

son Company, Chicago, Ill., has been appointed chairman of the AIEE committee on registration of engineers for 1946–47. Except for one year with the General Electric Company, Schenectady, N. Y., his entire professional career has been with the Commonwealth Edison Company which he served variously as cable engineer, substa-

T. G. LeClair

tion field engineer, engineer of system protection, and development engineer, before his recent appointment as staff engineer. Mr. LeClair has served on many committees and has been generally active in Institute affairs. He is AIEE vice-president for the Great Lakes District for 1946–47. For further biographical details see *Electrical Engineering*, March 1946, page 132.

Thomas R. Rhea (A '41) engineer, chemical section, industrial engineering department, General Electric Company, Schenectady, N. Y., has been appointed 1946–47 chairman of the AIEE committee on electrochemistry and electrometallurgy of which he has been a member since 1942. Born on May 2, 1900, in Bonham, Tex.,

T. R. Rhea

Mr. Rhea received a bachelor of science degree from the Massachusetts Institute of Technology and a master of science degree from Union University. He entered the employ of the General Electric Company in 1924 as application and design engineer. He is a member of the Association of Iron and Steel Engineers.

H. K. Polk (A '45) formerly assistant superintendent of maintenance for the Western United Gas and Electric Company, Aurora, Ill., and **R. M. Wainwright** (A '37) formerly research engineer for the Montana–Dakota Utilities Company, Loma, Mont., have been named assistant professors of electrical engineering at the University of Illinois, Urbana. Professor Polk had been with the Western United company since 1936. During the war he taught the fundamentals of electrical engineering, a-c circuits, and power transmission and distribution in the War Training Program carried on for war workers under supervision of the university. Professor Wainwright spent three years during the war in Washington, D. C., with the War Department, where he directed the writing of books on fundamentals of radar and later was technical consultant with the Signal Corps on analysis of enemy equipment. Before joining the staff of Montana–Dakota Utilities in 1938, he had been associated with the Montana Power Company, Butte.

W. O. Kurtz (A '17, F '40) vice-president, Illinois Bell Telephone Company, Chicago, has retired. Mr. Kurtz was born in Minnesota in 1884 and was graduated from Cornell University in 1905. Immediately after his graduation Mr. Kurtz entered the employ of the New York Telephone Company and, before becoming chief engineer of the Illinois company in 1924, was associated with the Eastern group of Bell Telephone companies, the Bell Telephone Company of Pennsylvania, and the American Telephone and Telegraph Company. He was made general manager of the state area of the Illinois company in 1928 and of the Chicago area in 1930. In 1938 he was appointed vice-president. He is a member of the Western Society of Engineers.

P. M. Honnell (M '46) formerly colonel and member of the faculty of the department of chemistry and electricity of the United States Military Academy, West Point, N. Y., has joined the staff of the University of Illinois, Urbana. At West Point Colonel Honnell was in charge of the department laboratories and was director of the electronics course. He entered military service in 1941 as a member of the faculty of the Signal Corps School in Fort Monmouth, N. J. Colonel Honnell received the Legion of Merit for his work at the Military Academy. He holds the degrees of bachelor of science and electrical engineer from the Agricultural and Mechanical College of Texas, and the degree of master of science from Massachusetts Institute of Technology and from California Institute of Technology. He completed additional graduate work in Vienna, Austria, and Paris, France.

A. W. Clement (A '25, M '34) formerly lieutenant colonel, Army of the United States, has returned to Bell Telephone Laboratories, Inc., New York, N. Y. Colonel Clement had been with the laboratories from 1925 until he entered upon active duty as a captain in 1940. During his military service he conducted demonstrations of advanced types of radar and electronic fire control equipment in Hawaii and made a study of seacoast artillery matériel and operations in the western Pacific. In 1946 Colonel Clement was awarded the Legion of Merit for his wartime services.

G. R. Anderson (A '22, M '29) formerly director and chief engineer of the electrical division of Fairbanks, Morse, and Company, Beloit, Wis., has been appointed director of engineering of the company's Beloit works. Mr. Anderson has been associated with Fairbanks, Morse, and Company since 1922. **G. H. Herrick** (A '26, M '33) succeeds Mr. Anderson as chief engineer of the electrical division. Mr. Herrick, formerly section design engineer on synchronous machinery, has been with the company since 1928.

R. R. Newquist (A '40) formerly manager, Washington, D. C., district office, Allis-Chalmers Manufacturing Company, has been elected vice-president in charge of sales of Roots-Connersville Blower Corporation, Connersville, Ind. Prior to his affiliation with the Allis-Chalmers company, Mr. Newquist had been with the Reliance Electric and Engineering Company, Cleveland, Ohio, from 1929 to 1932 and the Louis Allis Company, Milwaukee, Wis., from 1932 to 1934.

T. C. Stephens (A '44) formerly instructor in electrical engineering, University of Iowa, Iowa City, and **A. H. Wulfsberg** (A '43) of Cedar Rapids, Iowa, have joined the research division of the Collins Radio Company, Cedar Rapids. A graduate of the State University of Iowa, Mr. Stephens was associated with the development of the proximity fuse. Mr. Wulfsberg, a graduate of the University of Minnesota, was employed by Sylvania Electric Products, Inc., during the war.

A. F. Darland (A '20, M '29) superintendent of the light division, Public Utilities Department, City of Tacoma (Wash.), since 1945, has returned to the United States Bureau of Reclamation's Columbia Basin Project headquarters, Coulee Dam, Wash., in an administrative position. Previous to his former affiliation with the Columbia Basin Project, 1934–45, Mr. Darland had been associated with the Public Utilities Department of the City of Tacoma from 1923 to 1934.

R. C. Graham (A '41) formerly assistant to the director of research, General Cable Corporation, Bayonne, N. J., has joined the staff of the Rome (N. Y.) Cable Corporation, as chief product engineer. Mr. Graham had been connected with the General Cable Corporation since 1930. During the war he served on government committees responsible for the development of telephone, radio, and radar cables.

W. E. Wickenden (A '07, F '39) president, Case School of Applied Science, Cleveland, Ohio, and junior past president of AIEE, has announced his intention of retiring August 31, 1947. Doctor Wickenden has been president of the Case School since 1929 and during his presidency more than half of its graduates have received their degrees. He has been responsible for the development of an evening division, a graduate school, and an organized program of research at the Case School. Widely known for his civic activities, Doctor Wickenden has been at various times a director of the Cleveland Chamber of Commerce, chairman of the Ohio Highway Planning Board, and a member of the Postwar Planning Council of Greater Cleveland, and of the distribution committee of the Cleveland Foundation. He is a director of the Apex Electrical and Manufacturing Company, of the Equity Savings and Loan Company, a trustee of the Cleveland Clinic Foundation, and a member of the board of trustees of Case and Lake Erie College. A fuller biography of Doctor Wickenden appears in the March 1945 issue of *Electrical Engineering*, pages 122–3.

W. A. Upham (A '29, M '42) formerly general superintendent of distribution, United Illuminating Company of New Haven and Bridgeport, Conn., has been appointed chief engineer in charge of engineering. Mr. Upham joined the company in 1927 as an electrical engineer and was appointed superintendent of distribution for the Bridgeport division in 1927. In 1940 he became general superintendent for both the New Haven and Bridgeport divisions.

O. C. Brill (A '08, M '20) engineer in charge of plant engineering administration, American Telephone and Telegraph Company, New York, N. Y., has retired. Mr. Brill entered the Bell System in 1910 as an employee of the Pacific Telephone and Telegraph Company. After serving as a major in the Signal Corps in World War I, he entered the operations and engineering department of the American Telephone and Telegraph Company. He since has had various plant maintenance, installation, and engineering assignments. Mr. Brill plans to live in Los Altos, Calif.

C. M. Lynge (M '22) formerly assistant works manager, General Electric Company, Bridgeport, Conn., has been appointed manager of manufacturing for the company's appliance and merchandise department. Mr. Lynge joined the General Electric Company after his graduation from Yale University in 1912. At first Mr. Lynge was assigned to Schenectady, N. Y., and later to Pittsfield, Mass. He was transferred to Bridgeport in 1920 as manufacturing engineer. In 1929 he was made assistant works manager and in 1945 was given the additional title of assistant manager of manufacturing for the appliance and merchandise department.

R. E. Mathes (A '37) formerly lieutenant in the United States Naval Reserve, Bureau of Ships, Washington, D. C., recently was released from active duty, and has joined Finch Telecommunications, Inc., Clifton, N. J., as chief engineering and plant manager. With the RCA Laboratories, New York, N. Y., since his graduation from the University of Minnesota in 1924, Mr. Mathes had worked on the development of facsimile equipment.

Samuel Seely (A '38, M '44) formerly member of the staff of the radiation laboratory, Massachusetts Institute of Technology, Cambridge, has been appointed associate professor of electronics at the postgraduate school of the United States Naval Academy, Annapolis, Md. Doctor Seely, a member of the staff of the department of electrical engineering of the College of the City of New York, N. Y., has been on leave of absence since 1941.

L. D. Martin (A '40, M '43) senior electrical engineer, United States Engineers, Atlanta, Ga., has been awarded the Army Service Forces Commendation for Meritorious Civilian Service. The citation was made in recognition of his "loyalty, initiative, and exemplary performance of duty . . . . from October 1942 to June 1946."

J. W. Weigt (A '19, M '26) formerly head of the railway, industrial truck and locomotive department, Electric Storage Battery Company, New York, N. Y., has been appointed manager of the New York branch of that company. Mr. Weigt entered the company's employ in 1920 as a salesman in the New York branch.

E. G. Martin (A '41) formerly staff member and engineering consultant with the radiation laboratory, Massachusetts Institute of Technology, and with the radio research laboratory, Harvard University, Cambridge, has become a partner and president of the Martin-Hubbard Corporation, engineering consultants, Boston, Mass.

D. T. Braymer (A '42) formerly western editor, *Electrical World*, Chicago, Ill., has been transferred to New York, N. Y., as managing editor. A 1933 graduate of Cornell University, Mr. Braymer joined the staff of *Electrical World* as editorial assistant in 1935, was made assistant editor in 1936, and western editor in 1939.

H. L. Brouse (A '32, M '35) development engineer, Crosley Corporation, Cincinnati, Ohio, and **E. J. Bussard** (A '25) chief radio development engineer, Crosley Radio Corporation, Cincinnati, Ohio, have received citations from the United States Navy for their contributions to the development of the variable-time proximity fuse.

H. H. Hausner (M '40) formerly chief research engineer, General Ceramics and Steatite Corporation, Keasbey, N. J., has established himself as a consulting engineer, in New York, N. Y. Doctor Hausner recently was appointed research associate with New York University, New York, and research consultant with the Ceramic Institute, Rutgers University, New Brunswick, N. J.

F. K. McCune (A '33, M '43) formerly assistant executive manager, General Electric Company, Lynn, Mass., has been appointed a member of the company's apparatus design engineering staff at Schenectady, N. Y. Mr. McCune entered the employ of the General Electric Company immediately after his graduation from the University of California in 1928.

Tomlinson Fort (A '27, M '35) manager, central station department, and **R. J. Weber** (M '45) manager of the central station and transformer division, Westinghouse Electric Corporation, East Pittsburgh, Pa., have been awarded the Westinghouse Order of Merit.

A. H. Chandler (A '44) engineer in the industrial engineering department, Consolidated Gas, Electric Light, and Power Company, Baltimore, Md., recently received a certificate of appreciation from the Third Service Command in recognition of his part in the Utilities Wartime Aid Program.

Lionel Swift (A '45) formerly engineer in charge of technical services, Quebec Power Company, Quebec, Canada, has been made assistant superintendent of the power division of the company. A graduate of McGill University, Mr. Swift joined the company in 1945.

F. C. Stockwell (A '12, M '27) professor and chairman of the department of electrical engineering, Stevens Institute of Technology, Hoboken, N. J., recently received the honorary degree of doctor of engineering from that institute.

Haraden Pratt (A '15, F '37) vice-president and chief engineer, American Cable and Radio Corporation, New York, N. Y., has been elected chairman of the Radio Technical Planning Board for one year beginning October 1, 1946. Mr. Pratt was among the communications industry representatives at the Bikini atomic bomb tests.

C. E. Clutts (A '31) formerly lieutenant commander, United States Naval Reserve, has returned to Bell Telephone Laboratories, Inc., New York, N. Y. Mr. Clutts was assigned to the electronic division of the Bureau of Ships, Washington, D. C.

Philo Holcomb (A '40, M '41) formerly general inspector, Western Union Telegraph Company, New York, N. Y., has been appointed traffic engineer of international communications. Mr. Holcomb is the inventer of the Varioplex communications system.

G. R. Henninger (A '22, F '43) AIEE editor, New York, N. Y., who during the war was colonel and chief of the maintenance data section, maintenance division of the Air Matériel Command, Wright Field, Dayton, Ohio, has received a certificate of meritorious service from the Army Air Forces. "His meritorious service," the certificate states, "has contributed to the successful accomplishment of the mission of the Army Air Forces in World War II."

W. J. Kozuchowski (A '41) formerly production engineer, radio district, Philadelphia (Pa.) Signal Corps Procurement District, is now chief engineer of the Electrical Transformer Company. Mr. Kozuchowski holds the degrees of bachelor of electrical engineering and bachelor of mechanical engineering from the College of the City of New York.

L. F. Munzer (A '31, M '46) formerly major in the United States Army Air Corps, has joined the staff of RCA Communications, Inc., Marion, Mass., as assistant engineer. Mr. Munzer, who was graduated from the College of the City of New York in 1926, previously had been employed by the RCA company at Turkerton, N. J.

Herbert Sherman (A '41) recently released from the United States Navy as a lieutenant, has rejoined the Signal Corps as a senior engineer attached to the Philadelphia Signal Corps Procurement District. He received the degree of bachelor of electrical engineering from the College of the City of New York in 1940.

Stephen Chaika (A '45) formerly lieutenant, United States Naval Reserve, has been made assistant project engineer with the Sperry Gyroscope Company, Mineola, N. Y. He is a 1943 graduate of the College of the City of New York.

R. M. Cunningham (A '40) of the operations and engineering department, American Telephone and Telegraph Company, New York, N. Y., has been placed in charge of the group handling depreciation practices in the operating results division.

Thurman Oakley (A '45) formerly meter superintendent, Illinois Power Company, Belleville, has been appointed superintendent of the Madisonville, Ky., light and power plant.

V. P. Hessler (A '20, F '43) professor and head of the electrical engineering department, University of Kansas, Lawrence, has become a consultant to the Naval Research Laboratory.

C. L. Sampson (A '35, M '39) general manager, Northwestern Bell Telephone Company, Des Moines, Iowa, also has been elected vice-president of the company.

O. W. Tuthill (M '45) formerly studies engineer, New Jersey Bell Telephone Company, Newark, has been appointed engineer of exchange plant extension.

OBITUARY ••••

Frank Whitney Smith (A '05, M '12) retired president of the Consolidated Edison Company of New York (N. Y.), Inc., died July 22, 1946. Born in Alden, N. Y., June 16, 1867, Mr. Smith traced his ancestry to Sir Francis Drake, Elizabethan admiral and explorer. Another ancestor fought with the Continental Army. Mr. Smith commenced his utility career as office boy for the United States Illuminating Company, New York, in 1880, three months after Edison's invention of the incandescent lamp. Three years later he became general clerk and in 1889 general paymaster of the company's successor, the United Electric Light and Power Company. Thereafter he served as assistant auditor, assistant secretary, and secretary of the company. He was elected a director in 1902 and secretary of the Brush Electric Illuminating Company in 1905. He was named vice-president in 1912 and general manager in 1916. He was elected chairman of the board of directors of the New York and Queens Electric Light and Power Company in 1926 and in 1929 president of the Brush Electric Illuminating Company. In 1931 he became vice-president of the New York Edison Company and in 1932 president. He continued in that position after the Consolidated Edison Company of New York was incorporated until he retired in 1937. He was at one time president of the Brooklyn Edison Company. For many years he was a director of the Brooklyn Edison Company, the Westchester Lighting Company, the Yonkers Electric Light and Power Company, the Consolidated Telegraph and Electrical Subways Companies, and the New York Steam and Tarrytown Terminal Corporations. He held various offices in the now defunct National Electric Light Association. He was president of the Electric Vehicle Association of America in 1923. With H. C. Cushing, Jr., he was author of "The Electric Vehicle Handbook." He was a member of the Electrical Association of New York, the New York Electrical Society, and the Engineers' Club of New York. He was a trustee of the Northwestern Mutual Life Insurance Company and the Waldorf Astoria Corporation.

Alexander Russell Stevenson, Jr. (A '20, F '37) staff assistant to the vice-president in charge of engineering, General Electric Company, Schenectady, N. Y., died August 28, 1946. Doctor Stevenson, who was born May 28, 1893, in Schenectady, N. Y., received the degree of civil engineer from Princeton University in 1914. He received from Union College the degree of master of science in electrical engineering in 1915 and the degree of doctor of philosophy in 1917. He entered the United States Air Service in 1917 and was first officer in charge of testing at Langley Field, Va. He went to France later that year as officer in charge of the radio and electrical section of the Air Service and in 1918 was made officer in charge of flying and testing. He entered the power and mining engineering department of the General Electric Company in 1919 and was placed in charge of application engineering on synchronous motors and generators. In 1923 he was appointed to the staff of the vice-president in charge of engineering. Doctor Stevenson was responsible for the studies which led to the entrance of the company into household refrigeration manufacturing. He assisted Doctor Robert E. Doherty (F '39) in starting an advanced course in engineering and since 1930 had directed the program for the company. He was secretary of the company's engineering council and assisted the company's six operating departments and the laboratories with their educational and training programs. Doctor Stevenson was a fellow of the American Society of Mechanical Engineers, a past president of the American Society of Refrigeration Engineers, and a past president of the Private Flyers Club. He was a member of the Society for the Promotion of Engineering Education, the first Jet-Propulsion Subcommittee of the National Advisory Committee for Aeronautics, and the Civilian Advisory Council of the Military Training Division, Army Ordnance Department.

Albert Sears Crane (A '04, M '13) retired hydraulic engineer, and former vice-president of the J. G. White Engineering Corporation, New York, N. Y., died August 26, 1946. Mr. Crane was born May 30, 1868, in Addison, N. Y., and was graduated from Cornell University with the degree of civil engineer in 1891. He was appointed assistant to the city engineer of Newton, Mass., after graduation and in 1895 became assistant engineer in the department of City Works, Brooklyn, N. Y. He subsequently held the positions of chief assistant engineer of the Michigan, Lake Superior Power Company plant, Sault Sainte Marie, in 1898; chief engineer, Lake Superior Power Company, Sault Sainte Marie, in 1901; and principal assistant engineer of the Sanitary District of Chicago, Ill., in 1902. He joined the J. G. White company as chief hydraulic engineer in 1905 and was named vice-president in 1913. He remained in that position until in 1928 he became a consulting hydraulic engineer. During his long career, Mr. Crane engaged in the construction of 30 large earth dams, 60 masonry dams, 40 hydroelectric stations, and 6 irrigation projects. He was a member of the American Society of Civil Engineers, the Western Society of Engineers and of the Cornell, New York Lawyers, and Brooklyn Engineers Clubs.

Stanley Compton Wilcox (A '38, M '41) retired electrical engineer, Cleveland, Ohio, died June 22, 1946. Mr. Wilcox was born March 10, 1890, in Cleveland and studied at the Case School of Applied Science. He commenced his career as district engineer for the Western Union Telegraph Company from 1913 to 1916. He was afterwards

facility engineer with the Ohio Bell Telephone Company, Cleveland, until 1919. As an instructor in electricity from 1920 to 1924, he served the Cleveland Board of Education. He joined the Durkee Electric Company as electrical engineer in 1929 and was chief electrical engineer for the Great Lakes Exposition from 1936 to 1938. In 1938 he became electrical engineer for Cuyahoga County, Cleveland. As such he designed and installed the light system for the city's Main Avenue Bridge Project which was pronounced the finest installation of viaduct lighting in America by the committee on street lighting of the Illuminating Engineering Society.

Harold Platt Daniels (A '02) retired electrical engineer of Clinton, N. Y., died July 1, 1946. Mr. Daniels, who was born in New York, N. Y., February 3, 1881, was graduated from Columbia University in 1902. He was employed in the electrical testing department of the General Electric Company, Schenectady, N. Y., and in 1903 was made head of turbine testing. In 1904 he was transferred to the lighting engineering department. From 1905 until his retirement he was associated with Peet and Powers, Inc., New York, for which he was secretary and director. In World War I Mr. Daniels supervised electrical work in the United States Bag Loading Plant, Seven Oaks, Va., and during the last war at the Quonset Point (R. I.) Naval Base.

MEMBERSHIP . . .

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Any member objecting to the election of any of these candidates should so inform the secretary before October 21, 1946, or December 21, 1946, if the applicant resides outside of the United States or Canada.

To Grade of Fellow

Wheeler, H. A., 259-09 Northern Blvd., Great Neck, N. Y.

1 to grade of Fellow

To Grade of Member

Bonner, J. A., General Elec. Co. Ltd., Witton, Birmingham, England.
Buralander, W. A., Rocky Mt. Eng. Co., Denver, Colo.
Butcher, W., General Elec. Co., Glasgow, Scotland.
Carpenter, N. G., Gulf States Utilities Co., Lake Charles, La.
Catlin, J. R., British Admiralty, Bath, Somerset, England.
de Leva, M. M., 29 Via Pastrengo, Turin, Italy.
Dorris, R. C., Westinghouse Elec. Corp., Bloomfield, N. J.
Dunbar, E., Potomac Elec. Pr. Co., Washington, D. C.
Edelman, J. E., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Esher, F. N., Sperry Gyroscope Co., Inc., Great Neck, N. Y.
Guna, G. J. T., R. A. Haunght, Toronto, Ontario, Canada.
Gupta, N. R., Public Health Engg. Dept., U. P. Lucknow, India.
Hahn, P. T., General Armature & Mfg. Co., Lock Haven, Pa.
Hill, W. W., Alabama Polytechnic Inst., Auburn, Ala.
Jones, A. A., Anaconda Wire & Cable Co., Hastings-on-Hudson 6, N. Y.
Lawton, C. S., Western Union Tel. Co., New York, N. Y.
Mac Gregor, R. M., Westinghouse Elec. Corp., East Pittsburgh, Pa.
McMann, I. H. S., Riverside and Dan River Cotton Mills, Danville, Va.
Murray, R. R., American Embassy, Teheran, Iran.
Payne, B. T., Nepsco Services, Inc., Augusta, Maine.
Rife, C. J., Bell Aircraft Corp., Buffalo, N. Y.
Schroeder, H. E., John Graham Architects & Engrs., Seattle, Wash.
Shore, H., Federal Machine & Welder Co., Warren, Ohio.
Smith, H., Davis Transformer Co., Concord, N. H.
Taylor, P. R., St. Regis Paper Co., East Pepperell, Mass.
Weller, G. W., Empire Steel Corp., Mansfield, Ohio.
Wilkes, F. M., Southwestern Gas & Elec. Co., Shreveport, La.
Woolgar, E. J., F/O—R.A.F.O., Air Ministry, South Cerney, Gloucestershire, England.

28 to grade of Member

To Grade of Associate

United States and Canada

1. North Eastern

Boggis, M. C., General Elec. Co., Schenectady, N. Y.
Bralley, M. L., General Elec. Co., Pittsfield, Mass.
Dickinson, T. M., General Elec. Co., Schenectady, N. Y.
Exnicios, R. B., General Elec. Co., Schenectady, N. Y.
Gundersen, N. A., Parker Bateman & Chase, Clinton, Mass.
Harrington, J. D., USN, Worcester, Mass.
Heiser, W. H., General Elec. Co., Pittsfield, Mass.
Hirst, J. M., Thayer School of Engg., Dartmouth College, Hanover, N. H.
Lazarek, C. J., Narra Elec. Co., Westerly, R. I.
Nauls, A. C., Union Elec. Co., Boston, Mass.
Parker, J. H., University of Maine, Orono, Maine.
Thalheimer, J. C., Jr., New England Tel. & Tel. Co., Boston, Mass.
Walter, W. E., General Elec. Co., Pittsfield, Mass.

2. Middle Eastern

Balentine, W. H., Edison-Splitdorf Corp., Bethlehem, Pa.
Balsam, L. L., General Elec. Co., Erie, Pa.
Barse, G. R., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Berlin, B. A., Heinemann Elec. Co., Trenton, N. J.
Bradstock, R. B., General Elec. Co., Erie, Pa.
Cole, J. R., Navy Dept., Bureau of Ships, Washington, D. C.
Dunkelman, L., Bureau of Ships, Navy Dept., Washington, D. C.
Farber, W. R., Westinghouse Elec. Corp., Sharon, Pa.
Garrahan, C. J. (re-election), Swarthmore College, Swarthmore, Pa.
Goldsmith, H. M., Philadelphia Elec. Co., Philadelphia, Pa.
Huntsman, O. A., General Elec. Co., Philadelphia, Pa.
Irby, J. G., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Lamb, J. H., Jr., E. I duPont de Nemours & Co., Wilmington, Del.
Manhart, R. A., RCA Victor Div., RCA, Camden, N. J.
Michel, R. W., National Cash Register Co., Dayton, Ohio.
Pickering, L. J., Koppers Co., Pittsburgh, Pa.
Reid, J. C., Jr., Nat'l. Bureau of Standards, Washington, D. C.
Rigie, B., National Advisory Comm. for Aeronautics, Cleveland, Ohio.
Sabol, J. T., Ohio Crankshaft Co., Cleveland, Ohio.
Schneider, J. L., North Elec. Mfg. Co., Galion, Ohio.
Scull, H. M., Capt., USN, Inspector of Naval Material, Cincinnati, Ohio.
Steen, C. R., Westinghouse Elec. Corp., E. Pittsburgh, Pa.
Thelin, J. S., National Cash Register Co., Dayton, Ohio.
Woodhull, J. H., Naval Ordnance Lab., Washington, D. C.

3. New York City

Cervino, C. A., International Business Machines Corp. New York, N. Y.
Israel, L. J., Westinghouse Elec. Corp., New York, N. Y.
James, E. W., Norden Laboratories Corp., New York, N. Y.
Kleeberg, U. F., Norden Laboratories, New York, N. Y.
Kult, M. L., Lieut., SC, USAAF, c/o PM, New York.
Nordo, L., Press Wireless Mfg. Co., Long Island City, N. Y.
Price, E. J., Consolidated Edison Co. of N. Y., Inc., New York, N. Y.
Simpson, S. A., Simpson Elec. Corp., New York, N. Y.
Sukstaus, A. (re-election), W. L. Maxson Corp., New York, N. Y.
Wallace, E. C., Specialties, Inc., Syosset, N. Y.

4. Southern

Buck, T. A., General Elec. Co., Atlanta, Ga.
Carver, M. L., Gulf States Utilities Co., Lake Charles, La.
Duchesne, J. G., Jr., Sperry Gyroscope Co., Inc., Savannah, Ga.
Early, J. R., The Okonite Co., Roanoke, Va.
Elrod, J. L., General Elec. Co., Raleigh, N. C.
McDonald, C. H., Southwestern Gas & Elec. Co., Shreveport, La.
Nolan, W. R., Southwestern Gas & Elec. Co., Shreveport, La.
Vandling, J. R., Carbide-Carbon Chemicals Co., Oak Ridge, Tenn.

5. Great Lakes

Baldasar, T. L., Westinghouse Elec. Corp., Chicago, Ill.
Bollero, J. P., Carnegie-Illinois Steel Corp., Chicago, Ill.
Brown, A., Jr., The Austin Co., Chicago, Ill.
Buerschinger, D. R., 714 Hubbard St., Green Bay, Wis.
Crooks, J. C., General Motors Corp., La Grange, Ill.
Dahl, A. W., Minnesota Pr. & Lt. Co., Duluth, Minn.
Freund, R. J., Swift & Co., Chicago, Ill.
Greene, R. H., The Austin Company, Chicago, Ill.
Klein, C. J., Bendix Aviation Corp., South Bend, Ind.
Levin, E. J., Western Elec. Co., Chicago, Ill.
Morrow, G. L., 5046 S. Greenwood, Chicago, Ill.
Nelson, I. W., Route 1, Box 1, Evansville, Minn.
Noeske, O. W., Allis-Chalmers Mfg. Co., West Allis, Wis.
Smilanic, N. A., Electro-Motive Div. of G.M.C., La Grange, Ill.
Stone, N. T., Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

7. South West

Cupples, J. J., Westinghouse Elec. Corp., St. Louis, Mo.
Johnson, B. G., Houston Lighting & Pr. Co., Houston, Tex.
Loftin, A. D., H. N. Roberts & Associates, Lubbock, Texas.

8. Pacific

Austin, E. D. S., Stone & Webster Eng. Corp., Los Angeles, Calif.
Clark, R. A., General Elec. Co., San Francisco, Calif.
Davis, A. L., General Elec. Co., Los Angeles, Calif.
Duacek, A. W., Ensign, USNR, FPO, San Francisco, Calif.
Franklin, W. W., Southern Calif. Water Co., Los Angeles, Calif.
Glenn, W. H., Jr., A. O. Smith Corp., Los Angeles, Calif.
Kaupp, W. J., Calif. Inst. of Tech., Pasadena, Calif.
King, B. G., Univ. of Southern Calif., Los Angeles, Calif.
Marshall, F. C., McColpin Christie Corp., Ltd., Los Angeles, Calif.
O'Roke, A. B., Pacific Gas & Elec. Co., Oakland, Calif.
Prewett, M. M., General Elec. Co., San Francisco, Calif.
Smith, A. W., Central Arizona Lt. & Pr. Co., Phoenix, Ariz.
Taylor, J. B., Calif. Inst. of Tech., Pasadena, Calif.
Wingfield, H. V., Dept. of the Interior, Los Angeles, Calif.

9. North West

Davis, F. H., Bonneville Pr. Adm., Portland, Oreg.
Lomas, G. E. (re-election), Bonneville Pr. Adm., Portland, Oreg.
Quist, F. F., General Elec. Co., Portland, Oreg.

10. Canada

Campbell, C. B., B. C. Elec. Ry. Co., Vancouver, B. C., Canada.
Hutchinson, D. C., Canadian Westinghouse Co., Calgary, Alberta, Canada.
Monty, G. J., Quebec Hydro-Electric Comm., Montreal, Que., Canada.
Morley, J. A., A. V. Roe Canada, Ltd., Toronto, Ont., Can.

Elsewhere

Bustamante, A., The Mexican Lt. & Pr. Co., Ltd., Mexico, D. F., Mexico.
Chang, L. C., Wuchang Electricity Works, Wuchang, China.
Galicia R., A., The Mexican Lt. & Pr. Co., Ltd., Mexico, D. F., Mexico.
Mier F., O. (re-election), Luscurain & Mier Co., Mexico, D. F., Mexico.
Own, K. M., Tsingtao Electricity Works, Tsingtao, Shantung, China.
Piza, J., Puerto Rico Water Resources Authority, Ponce, Puerto Rico.
Suares F., E., Instituto Nacional Obras Sanitarias, Caracas, Venezuela, South America.
Vazquez G., L., General Elec., S. A., Mexico D. F., Mexico.
White, M. J. H., Northampton Elec. Lt. & Pr. Co. Ltd., Northampton, England.
Whitty, W. H. R., Messrs. A. Reyrolle & Co., Ltd., Heborn-on-Tyne, England.
Yu, S. C., Kweiyang Electricity Works, Kweiyang, Kweichow, China.

Total to grade of Associate
United States and Canada, 94
Elsewhere, 11

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(Term expires July 31, 1947)

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(Term expires July 31, 1947)

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(Term expires July 31, 1948)

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	(Terms expire July 31, 1947)	
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3	O. E. BUCKLEY	New York, N. Y.
5	T. G. LeCLAIR	Chicago, Ill.
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9	C. F. TERRELL	Seattle, Wash.
	(Terms expire July 31, 1948)	

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(Terms expire July 31, 1948)

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(Terms expire July 31, 1949)

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(Terms expire July 31, 1950)

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(Term expires July 31, 1947)

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(Term expires July 31, 1947)

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BRAZIL—Richard H. Bowles, Sao Paulo Tramway Light and Power Company, Sao Paulo.

ENGLAND—A. P. M. Fleming, Metropolitan-Vickers Electric Company, Trafford Park, Manchester 17.

INDIA, NORTHERN—N. Thornton, P.W.D., Electricity Branch, 11 Bahawalpur Road, Lahore, Punjab.

INDIA, SOUTHERN—N. N. Iengar, The Tata Power Company Ltd., Bombay House, Bruce Street, Fort Bombay.

SWEDEN—A. F. Enstrom, Ingeniorsvetenskapsakademien, Stockholm 5.

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(Terms expire July 31, 1947)
C. R. Freehafer — C. A. Powel — David Sarnoff
(Terms expire July 31, 1948)
O. E. Buckley — A. E. Knowlton — H. E. Strang
(Terms expire July 31, 1949)
C. V. Christie — Zay Jeffries — Harold Pender
(Terms expire July 31, 1950)
C. A. Corney — S. M. Dean, *chairman* — I. M. Stein
(Terms expire July 31, 1951)

Elected by the board of directors from its own membership for term of two years

J. R. North — D. A. Quarles — H. B. Wolf
(Terms expire July 31, 1947)
P. L. Alger — R. T. Henry — E. P. Yerkes
(Terms expire July 31, 1948)

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J. Elmer Housley, president
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(Terms expire July 31, 1947)
J. W. Barker — Ernst Weber
(Terms expire July 31, 1948)
H. E. Strang — C. H. Willis
(Terms expire July 31, 1949)

Headquarters

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H. H. Henline — D. A. Quarles

Lamme Medal

W. A. Del Mar — John C. Parker, *chairman* — Philip Sporn
(Terms expire July 31, 1947)
H. L. Hazen — V. M. Montsinger — G. A. Waters
(Terms expire July 31, 1948)
N. S. Hibshman — T. G. LeClair — A. C. Monteith
(Terms expire July 31, 1949)

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J. F. Fairman, *chairman*, Consolidated Edison Company of New York, Inc., 4 Irving Place, New York 3, N. Y.
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Prizes, Award of Institute

M. D. Hooven, *chairman*, Public Service Electric and Gas Company, 80 Park Place, Newark 1, N. J.
C. S. Rich, *secretary*, AIEE, 33 West 39th Street, New York 18, N. Y.
J. W. Barker — J. J. Pilliod
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Publication

C. F. Wagner, *chairman*, Westinghouse Electric Corporation, East Pittsburgh, Pa.
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R. K. Honaman — J. J. Orr
B. M. Jones — H. H. Race
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Publicity, Institute

R. K. Honaman, *chairman*, 463 West Street, New York 14, N. Y.
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E. E. Dorting — C. R. Jones
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T. G. LeClair, *chairman*, Commonwealth Edison Company, 72 West Adams Street, Chicago 90, Ill.
J. E. Hobson, *secretary*, Illinois Institute of Technology, 3300 Federal Street, Chicago 16, Ill.

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Research

J. W. Barker, *chairman*, Research Corporation, 405 Lexington Avenue, New York 17, N. Y.

P. L. Alger — E. L. Moreland
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Safety

L. F. Adams, *chairman*, General Electric Company, Schenectady 5, N. Y.
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A. B. Smith, *secretary*, National Electrical Manufacturers Association, 155 East 44th Street, New York 17, N. Y.

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V. P. Hessler — C. S. Purnell
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Ex officio
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Standards

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R. L. Jones, *secretary*, 463 West Street, New York 14, N. Y.
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Chairmen of working and co-ordinating committees of the Standards committee
Chairmen of AIEE technical committees
Chairmen of AIEE delegations on other standardizing bodies or sole representatives thereon
President, United States National Committee of the International Electrotechnical Commission

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D. E. Moat, *chairman*, Leeds and Northrup Company, 1800 Keith Building, Cleveland 15, Ohio

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Student Branch counselors

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M. D. Hooven, *chairman*, Public Service Electric and Gas Company, 80 Park Place, Newark 1, N. J.
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C. S. Rich, *secretary*, AIEE, 33 West 39th Street, New York 18, N. Y.

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I. W. Gross — Frank Thornton, Jr.
F. E. Johnson, Jr. — C. C. Whipple
T. A. Worcester

Ex officio
J. F. Fairman, *chairman*, committee on planning and co-ordinator
L. F. Adams, *chairman*, committee on safety
W. P. Dobson, *chairman*, Standards committee
Chairmen of all technical committees

Technical Committees

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J. D. Miner, *chairman*, Aviation Engineering Department, Westinghouse Electric Corporation, Lima, Ohio
F. M. Roberts, *vice-chairman*, industrial engineering division, General Electric Company, Schenectady 5, N. Y.
A. F. Pelster, *secretary*, Westinghouse Electric Corporation, Lima, Ohio

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Harold R. Brown — Earl G. Ports
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J. F. Calvert — Raymond Rugge
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Chas. Kingsley, Jr. — F. H. Walker
R. A. Millermaster — W. W. West
F. O. Wiman

Automatic Stations

George S. Whitlow, *chairman*, Union Electric Company of Missouri, 315 North 12th Boulevard, Saint Louis, Mo.

J. A. Adams — E. E. George
Harris Barber — K. B. Hoffman
G. W. Bean — I. T. Knight
L. B. Bogan — G. S. Lunge
W. A. Derr — Perry Peterson
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Basic Sciences

J. D. Tebo, *chairman*, Bell Telephone Laboratories, Inc., 463 West Street, New York 14, N. Y.

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F. C. Lindvall — Ernst Weber

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H. I. Romnes, *secretary*, American Tel. & Tel. Company, 195 Broadway, New York 7, N. Y.

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Domestic and Commercial Applications

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Wesley Weinerth, *secretary*, Philadelphia Electric Company, 2301 Market Street, Philadelphia 3, Pa.

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E. B. Kurtz — C. E. Tucker
E. A. Loew — C. E. Tuites
A. C. Monteith — E. A. Walker
J. A. Northcott, Jr. — R. W. Warner
A. R. Zimmer

Electric Machinery

M. S. Aldacre, *chairman*, Commonwealth Edison Company, 72 West Adams Street, Chicago 90, Ill.
C. P. Potter, *vice-chairman*, Wagner Electric Corporation, 6400 Plymouth Ave., St. Louis 14, Mo.
W. C. Sealy, *secretary*, Allis-Chalmers Manufacturing Company, Milwaukee 1, Wis.

E. H. Alexander — C. J. Koch
Sterling Beckwith — T. C. Lloyd
Theodore Bratten — C. M. Lovell
F. S. Brown — G. W. McIver, Jr.
B. M. Cain — R. C. Moore
J. F. Calvert — T. H. Morgan
G. T. Harness — L. M. Robertson
F. E. Harrell — M. L. Schmidt
C. B. Hathaway — J. F. Sellers
R. A. Hopkins — H. D. Sill
W. R. Hough — H. R. Sills
E. K. Kane — F. D. Snyder
F. P. Kaspar — F. H. Trickey
C. E. Kilbourne — C. G. Veinott
L. A. Kilgore — R. L. Webb

Subcommittee chairmen
F. S. Brown, transformer
C. B. Hathaway, d-c machinery
W. R. Hough, induction machinery
C. E. Kilbourne, synchronous machinery
T. C. Lloyd, test code co-ordinating
R. L. Webb, insulation resistance

Technical Committees (continued)

Electric Welding

G. W. Garman, *chairman*, General Electric Company, 1 River Road, Schenectady 5, N. Y.

C. A. Adams	J. Harold Lampe
E. M. Callender	C. I. MacGuffie
G. M. Chute, Jr.	L. B. Potter
C. N. Clark	Sam Shiozawa
W. E. Crawford	C. E. Smith
E. W. Davis	H. W. Snyder
J. F. Deffenbaugh	W. Spraragen
G. H. Fett	E. F. Steinert
K. L. Hansen	L. K. Stringham
W. F. Hess	E. H. Vedder
C. E. Humble	J. R. Wirt

M. Zucker

Electrochemistry and Electrometallurgy

T. R. Rhea, *chairman*, General Electric Company, Schenectady 5, N. Y.

F. R. Benedict, *vice-chairman*, Room 11-L-17, Westinghouse Electric Corporation, East Pittsburgh, Pa.

W. C. Kalb, *secretary*, National Carbon Company, Inc., Carbon Products Division, P.O. Box 6087, Cleveland 1, Ohio

F. T. Chesnut	F. L. Lawton
L. H. Fletemeyer	D. H. Levy
L. O. Grondahl	Waldo Porter
W. E. Gutzwiller	J. B. Rice
J. D. Harper	Leroy W. Roush
J. E. Hobson	F. O. Schnure
Rollin Kennard	W. R. Schofield
E. L. Kirk	N. R. Stansel
W. B. Kouwenhoven	E. R. Whitehead

Electronics

W. R. G. Baker, *chairman*, General Electric Company, electronics department, Thompson Road, Syracuse, N. Y.

C. H. Willis, *vice-chairman*, Princeton University, Princeton, N. J.

W. G. Dow, *secretary*, University of Michigan, Ann Arbor, Mich.

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G. J. Crowden	D.A. Quarles
A. V. Eastman	W. G. Roman
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William Fraser	E. T. Sherwood
A. P. Godsho	Thomas Spooner
J. A. Green	B. F. Teilkamp
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L. C. F. Horle	F. N. Tompkins
S. B. Ingram	H. M. Turner
J. P. Jordan	D. G. Ulrey
L. A. Kilgore	E. H. Vedder
J. D. Leitch	Wm. Comings White

H. Winograd

Industrial Control Devices

E. U. Lassen, *chairman*, Cutler-Hammer, Inc., 315 North 12th Street, Milwaukee 1, Wis.

J. D. Leitch, *vice-chairman*, The Electric Controller and Manufacturing Company, 2700 East 79th Street, Cleveland 4, Ohio

E. F. Mekelburg, *secretary*, industry controller division, Square D Company, 4041 North Richards Street, Milwaukee 12, Wis.

E. H. Alexander	R. W. Jones
H. H. Angel	L. H. Matthias
G. S. Brown	M. Michel
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R. F. Danner	T. B. Montgomery
W. J. Fleming	J. W. Picking
D. K. Frost	L. T. Rader
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Light, Production and Application of

S. G. Hibben, *chairman*, The Westinghouse Lamp Division, Bloomfield, N. J.

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H. E. Mahan	I. A. Yost

Industrial Power Applications

Herbert Speight, *chairman*, Westinghouse Electric Corporation, 40 Wall Street, New York 5, N. Y.

S. F. French, *vice-chairman*, Anaconda Copper Mining Company, 20 Broadway, New York 4, N. Y.

L. A. Umansky, *secretary*, General Electric Company, Schenectady 5, N. Y.

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F. R. Benedict	E. G. Morehouse
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L. N. Grier	E. E. Turkington
John Grotzinger	J. M. Webb
W. R. Harmer	C. C. Whipple
K. W. John	R. T. Woodruff

Instruments and Measurements

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E. D. Doyle, *vice-chairman*, Leeds and Northrup Company, 4901 Stenton Avenue, Philadelphia 44, Pa.

C. T. Burke, *secretary*, General Radio Company, 275 Massachusetts Ave., Cambridge 39, Mass.

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A. J. Grant	F. B. Scott
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Land Transportation

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E. V. Sayles, *vice-chairman*, Consumers Power Company, Jackson, Mich.

I. W. Gross, *secretary*, American Gas and Electric Service Corporation, 30 Church Street, New York 7, N. Y.

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Marine Transportation

W. H. Reed, *chairman*, Bruce Electric Company, 196 West Houston Street, New York 14, N. Y.

O. A. Wilde, *vice-chairman*, Sun Shipbuilding and Dry Dock Company, Chester, Pa.

W. N. Zippler, *secretary*, Gibbs and Cox, Inc., 1 Broadway, New York 4, N. Y.

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W. B. Armstrong	J. E. Jones
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Power Generation

M. J. Steinberg, *chairman*, Consolidated Edison Company of New York, Inc., 4 Irving Place, New York 3, N. Y.

B. G. A. Skrotzki, *secretary*, *Power*, 330 West 42nd Street, New York 18, N. Y.

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S. Beckwith	F. M. Lewis
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C. B. Kelley	W. R. Way
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C. M. Laffoon	R. L. Witzke

Protective Devices

H. W. Collins, *chairman*, Detroit Edison Company, 2000 Second Avenue, Detroit 26, Mich.

W. A. Lewis, *vice-chairman*, Armour Research Foundation, 35 West 33rd Street, Chicago 16, Ill.

L. F. Kennedy, *secretary*, central station department, General Electric Company, Schenectady 5, N. Y.

H. D. Braley	F. R. Longley
W. R. Brownlee	J. R. North
O. E. Charlton	H. V. Nye
William Deans	H. H. Rudd
H. W. Haberl	W. J. Rudge
H. J. Lingal	J. H. Vivian

Subcommittee chairmen

W. R. Brownlee, relays

H. J. Lingal, circuit breakers and assembled switchgear

F. R. Longley, fault current limiting devices

H. H. Rudd, switches, fuses, and insulators

W. J. Rudge, lightning protective devices

Therapeutics, Applications of Electrity to

W. B. Kouwenhoven, *chairman*, Johns Hopkins University, Baltimore 18, Md.

L. L. Call	H. D. Moreland
E. E. Charlton	H. C. Rentschler
F. B. Claussen	W. R. Smith
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Institute Representatives

Aeronautical Electrical Equipment Standardization

J. R. North, liaison representative with NASC and SAE

Alfred Noble Prize Committee, ASCE

Robin Beach

American Association for the Advancement of Science, Council

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American Co-ordinating Committee on Corrosion

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American Standards Association, Standards Council

W. P. Dobson R. T. Henry H. S. Osborne

Alternates

H. E. Farrer E. B. Paxton J. J. Pilliod

(Continued on page 482)

Local Sections of the Institute

Name	District	When Organized	Membership Aug. 1, 1946	Chairman	Secretary	Secretary's Address
Akron	2	Aug. 12, '20	120	Paul S. Bechtol	A. J. B. Fairburn	College of Engg., University of Akron, Akron 4, Ohio
Alabama	4	May 22, '29	101	C. F. Sittloh	M. M. Collins	General Electric Co., P.O. Box 2602, Birmingham, 2, Ala.
Arizona	8	Mar. 22, '41	73	Irwin W. Best	F. J. Groat	Bureau of Reclamation, P.O. Box 2071, Phoenix, Ariz.
Beaumont	7	June 27, '45	75	N. C. Spencer	C. A. Daniel	P.O. Box 2870, Beaumont, Tex.
Boston	1	Feb. 3, '03	694	T. S. Gray	L. F. Cleveland	Northwestern University, 360 Huntington Ave., Boston 15, Mass.
Central Indiana	5	Jan. 12, '12	193	E. G. Hinshaw	W. H. Bollinger	1670 Allison, Indianapolis 8, Ind.
Chicago	5	1893	1,235	L. R. Janes	J. E. Hobson	Armour Research Foundation, 35 W. 33rd St., Chicago 16, Ill.
Cincinnati	2	June 30, '20	189	W. C. Osterbrock	L. H. McLaughlin	225 E. Fourth St., Cincinnati 2, Ohio
Cleveland	2	Sept. 27, '07	512	J. C. Strasbourger	H. W. Sussman	3689 Glencairn Road, Shaker Heights 20, Ohio
Columbus	2	Mar. 17, '22	94	E. D. Ayres	E. E. Kimberly	Ohio State University, Columbus, Ohio
Connecticut	1	Apr. 16, '21	435	Harry F. Brown	Elmer G. Horton	Westinghouse Electric Corp., P.O. Box 1817, New Haven 8, Conn.
Dayton	2	June 9, '43	258	W. A. Dynes	W. A. Barden	545 Daytona Parkway, Dayton 6, Ohio
Denver	6	May 18, '15	284	L. A. Stenger	M. H. Kight	U. S. Bureau of Reclamation, Denver, Colo.
East Tennessee	4	Sept. 2, '36	284	F. A. Hoeke	R. M. Alspaugh	T.V.A., Union Building, Knoxville, Tenn.
Erie	2	Jan. 11, '18	87	Lanier Greer	Wilbur C. Brown	General Electric Co., East Lake Road, Erie, Pa.
Florida	4	Jan. 28, '31	155	M. L. Barre	C. H. Summers	Florida Power & Light Co., Miami, Fla.
Fort Wayne	5	Aug. 14, '08	109	S. W. Winje	E. A. Linke	813 West Packard, Fort Wayne 6, Ind.
Georgia	4	Jan. 14, '04	179	Gordon F. Price	Robert O. Loomis	Georgia Power Co., Atlanta 1, Ga.
Houston	7	Aug. 7, '28	187	R. S. Kersh	H. C. Dillingham	Texas A. & M. College, College Station, Tex.
Illinois Valley	5	June 30, '45	80	Thomas A. Hopkins	C. T. Borchelt	1118 N. Glen Oak Ave., Peoria 4, Ill.
Iowa	5	June 29, '29	104	Richard F. Castner	Wilton R. Abbott	Iowa State College, Ames, Iowa
Ithaca	1	Oct. 15, '02	99	W. H. Erickson	P. D. Ankrum	School of Elec. Engg., Cornell University, Ithaca, N. Y.
Kansas City	7	Apr. 14, '16	193	C. Myron Lytle	Joel P. Kesler	Westinghouse Electric Corp., 101 W. 11th St., Kansas City 6, Mo.
Lehigh Valley	2	Apr. 16, '21	216	R. E. Neidig	A. L. Price	173 S. Church St., Hazleton, Pa.
Los Angeles	8	May 19, '08	900	E. W. Morris	Bradley Cozzens	P.O. Box 3669 Terminal Annex, Los Angeles, Calif.
Louisville	4	Oct. 15, '26	82	L. W. Anderson	Harry Hadsel	Amer. Elevator & Machine Co., 500 E. Main St., Louisville 2, Ky.
Lynn	1	Aug. 22, '11	217	R. G. Connors	B. M. Cain	General Electric Co., 3rd-74, 920 Western Ave., West Lynn, Mass.
Madison	5	Jan. 8, '09	90	Carl C. Crane	B. C. Lueders	532 Oak St., Baraboo, Wis.
Mansfield	2	Mar. 6, '39	60	Eric Brooke	C. W. Freeman	North Electric Mfg. Co., Galion, Ohio
Maryland	2	Dec. 16, '04	460	H. H. Angel	R. L. McCoy	Locke Insulator Corp., Baltimore, Md.
Memphis	4	May 22, '30	117	W. R. Moyers, Jr.	M. G. Sifford	Westinghouse Elec. Supply Co., 366 Madison Ave., Memphis 3, Tenn.
Mexico	7	June 29, '22	195	O. R. Enriquez	Antonio Baca	33 Palma St., Room 210, Mexico D. F., Mexico
Michigan	5	Jan. 13, '11	562	G. M. Chute	A. W. Rauth	Consumers Power Co., 212 Michigan Ave., Jackson, Mich.
Milwaukee	5	Feb. 11, '10	500	Walther Richter	F. J. Van Zeeland	Milwaukee School of Engg., 1020 N. Broadway, Milwaukee, Wis.
Minnesota	5	Apr. 7, '02	184	H. E. Hartig	Donald C. Gray	American Hotel & Derrick Co., 63 S. Robert St., St. Paul 1, Minn.
Montana	9	June 24, '31	72	E. W. Williams	N. H. Hilke	International Business Machines Co., Helena, Mont.
Montreal	10	Apr. 16, '43	245	W. R. Simmons	M. C. Thurling	Can. Gen. Elec. Co. Ltd., 1000 Beaver Hall Hill, Montreal, Que.
Muscle Shoals	4	Feb. 18, '38	23	Ernest L. Bishop	Lyle W. Jenkins	922 Glendale St., Florence, Ala.
Nebraska	6	Jan. 21, '25	60	Max Mattison	I. M. Ellestad	Northwestern Bell Telephone Co., Omaha, Nebr.
New Mexico-West Texas	7	Mar. 7, '40	68	Roy M. Walker	Oscar H. Gutsch	2717 E. Missouri St., El Paso, Tex.
New Orleans	4	Dec. 8, '33	185	F. E. Johnson	E. I. Blanchard	Louisiana P. & L. Co., 433 Metairie Road, New Orleans 20, La.
New York	3	Dec. 10, '19	4,175	J. H. Pilkington	P. C. Cromwell	New York University, University Heights, New York 53, N. Y.
Niagara Frontier	1	Feb. 10, '25	232	R. G. Harper	E. T. Nicholson	Buffalo Niagara Electric Corp., 93 Dewey Ave., Buffalo 14, N. Y.
North Carolina	4	Mar. 21, '29	174	G. F. Stratton	C. W. Moseley	1129 Greenwood Cliff, Charlotte 3, N. C.
North Texas	7	May 18, '28	272	H. K. Doyle	W. C. Fowler	Hotel Texas, Fort Worth, Tex.
Oklahoma City	7	Feb. 16, '22	133	J. L. Jones	H. E. Brashear	Southwestern Bell Telephone Co., Oklahoma City, Okla.
Philadelphia	2	Feb. 18, '03	1,067	H. A. Dambly	W. R. Clark	Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia 44, Pa.
Pittsburgh	2	Oct. 13, '02	772	J. B. Hodtum	A. C. Monteith	Westinghouse Electric Corp., East Pittsburgh, Pa.
Pittsfield	1	Mar. 25, '04	221	D. D. MacCarthy	W. E. Birchard	Motor Engg. Div., General Electric Co., Pittsfield, Mass.
Portland	9	May 18, '09	302	W. Morgan Allen	M. D. Duffy	Northwestern Electric Co., 920 S. W. Sixth Ave., Portland 4, Oreg.
Providence	1	Mar. 12, '20	112	C. H. Parker	G. E. Andrews, Jr.	Engg. Dept., Narragansett Electric Co., Providence 1, R. I.
Rochester	1	Oct. 9, '14	154	G. R. Town	A. F. Martin	Bausch & Lomb Optical Co., 635 St. Paul St., Rochester 2, N. Y.
St. Louis	7	Jan. 14, '03	377	O. T. Farry	R. W. Gaskins	Union Electric Co. of Missouri, 12th & Locust Sts., St. Louis 1, Mo.
San Diego	8	Jan. 18, '39	110	G. F. McCabe	H. A. Cordes	General Electric Co., 861 Sixth Ave., San Diego 1 Calif.
San Francisco	8	Dec. 23, '04	839	L. Tiller	I. L. Buckley	Pacific Gas & Electric Co., 245 Market St., San Francisco 6, Calif.
Schenectady	1	Jan. 26, '03	700	R. V. Shepherd	J. C. Page	Central Station Engg. Div., General Elec. Co., Schenectady 5, N. Y.
Seattle	9	Jan. 19, '04	310	A. V. Eastman	John M. Nelson	1015 Third Ave., Seattle 4, Wash.
Sharon	2	Dec. 11, '25	145	C. W. Miller	R. L. Brown	1619 McDowell St., Sharon, Pa.
South Bend	5	Feb. 26, '41	76	H. E. Ellithorn	A. J. Quigley	1019 N. Frances St., South Bend 17, Ind.
South Carolina	4	Mar. 2, '40	52	J. L. Weeks	Charles O. Warren	525 Woodrow St., Columbia, S. C.
South Texas	7	May 23, '30	83	O. T. Lodal	C. G. Krause	City Pub. Service Bd., 201-203 N. St. Mary's St., San Antonio 5, Tex.
Spokane	9	Feb. 14, '13	122	D. H. Olney	O. W. Hurd	Bonneville Power Administration, Title Bldg., Spokane 8, Wash.
Springfield	1	June 29, '22	66	W. S. Scherring	J. L. Hyland	Western Massachusetts Electric Co., Turners Falls, Mass.
Syracuse	1	Aug. 12, '20	160	L. J. Audlin	W. C. Jenkins	Westinghouse Electric Corp., 700 W. Genesee St., Syracuse 4, N. Y.
Toledo	2	June 3, '07	89	W. E. Boruh	W. M. Campbell	2145 Central Grove Ave., Toledo, Ohio
Toronto	10	Sept. 30, '03	466	A. R. Zimmer	H. Osborne	Ferranti Electric Ltd., Mount Dennis, Toronto, Ont.
Tulsa	7	Oct. 1, '37	100	E. F. Patterson	S. C. Wright	Southwestern Bell Telephone Co., 420 S. Detroit, Tulsa, Okla.
Urbana	5	Nov. 25, '02	53	E. A. Reid	C. A. Keener	308 Elec. Engg. Lab., University of Illinois, Urbana, Ill.
Utah	9	Mar. 9, '17	94	J. R. Jarvis	John A. McDonald	General Electric Co., P.O. Box 779, Salt Lake City, Utah
Vancouver	10	Aug. 22, '11	126	F. J. Bartholomew	F. H. Hedley	Can. Westinghouse Co. Ltd., 1418 Marine Bldg., Vancouver, B. C.
Virginia	4	May 19, '22	151	C. H. Smoke	William C. Jones	Box 1707, Norfolk 1, Va.
Washington	2	Apr. 9, '03	709	F. S. Black	Dixon Lewis	Alum. Co. of Amer., 605 Southern Bldg., Washington 5, D. C.
West Virginia	2	Apr. 9, '40	79	E. M. Hansford	W. E. Nuhfer	Appalachian Electric Power Co., Cabin Creek, W. Va.
Wichita	7	Sept. 16, '37	82	R. D. Finnell	C. W. Halferty	Kansas Gas & Electric Co., 201 N. Market St., Wichita 1, Kans.
Worcester	1	Feb. 18, '20	66	T. H. Morgan	B. F. Hammarstrom	Heald Machine Co., New Bond St., Worcester 6, Mass.
Total Sections	75		22,645			

Local Subsections of the Institute

Name	Chairman	Secretary	Secretary's Address
Local Subsections			
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Arrowhead (Minnesota Section)	R. H. Holmes	Arthur C. Smythe	Minnesota Power & Light Co., Duluth, Minn.
Boulder Dam (Los Angeles Section)	C. L. Westmann	C. L. Collins	519 Birch St., Boulder City, Nev.
Canton (Akron Section)	R. C. Wey	H. E. Rue	310 Fairview St., N. Canton, Ohio
Charleston (South Carolina Section)	Dean H. Davis	Max G. Toole	P.O. Box 42, U. S. Navy Yard, Charleston, S. C.
Charlotte (North Carolina Section)	E. Robert Davis	W. B. White	210 E. Sixth St., Charlotte, N. C.
Florida West Coast (Tampa) (Florida Section)	I. C. Matheson		
Fresno (San Francisco Section)	J. P. Price	G. A. Collins	San Joaquin Light & Power Div., Pacific Gas & Electric Co., Fresno, Calif.
Great Falls (Montana Section)		D. A. Johnson	Mt. States Tel. & Tel. Co., 401 First Ave. N., Great Falls, Mont.
Hamilton (Toronto Section)	J. F. McDiarmid	C. E. Moorhouse	Canadian Westinghouse Ltd., Hamilton, Ont.
Hampton Roads (Virginia Section)	W. G. Gardner	F. U. Ross	Virginia Electric & Power Co., Portsmouth, Va.
Jacksonville (Florida Section)	M. L. Barre		
Lake Charles (New Orleans Section)	F. I. Stalnecker	J. A. Carruth	Gulf State Utilities Co., 314 Blood St., Lake Charles, La.
Lancaster–York (Maryland Section)	H. J. Stewart	J. L. Stauffer	Pennsylvania Power & Light Co., Griest Bldg., Lancaster, Pa.
Little Rock (Memphis Section)	J. A. Hunter	O. W. Waller	Box 2100, Little Rock, Ark.
Miami (Florida Section)	P. J. Carlin		
Niagara Falls (Niagara Frontier Section)	G. A. Zehr	G. R. Staker	203—79th St., Niagara Falls, N. Y.
Niagara District (Toronto Section)	J. I. Gram	W. G. Barr	1888 Main St., Niagara Falls, Ont.
Ottawa (Montreal Section)	B. G. Ballard	J. H. Simpson	National Research Council, Ottawa, Ont.
Panhandle (North Texas Section)	C. V. Bullen	H. O. Hodson	Southwestern Public Service Co., 420 Polk St., Amarillo, Tex.
Richmond (Virginia Section)	W. T. Johns, Jr.	H. A. Frazier	System Engg. Dept., Virginia Elec. & Power Co., Richmond, Va.
Rock River Valley (Madison Section)	R. E. Schuette	Royce E. Johnson	Barber-Colman Company, Rockford, Ill.
Sacramento (San Francisco Section)	James C. Coombs	James R. Miller	3991 Third Ave., Sacramento, Calif.
Saginaw Valley (Michigan Section)	Melvin L. Manning	Gordon S. Marvin	1007 Bradley Ave., Flint 3, Mich.
Shreveport (New Orleans Section)	W. J. Googe	W. N. Petzinger	General Electric Co., 206 Market St., Shreveport, La.
Wilmington (Philadelphia Section)	F. T. Grear	E. W. Randall	E. I. du Pont de Nemours & Co., Wilmington, Del.
Zanesville (Columbus Section)	George W. Miller	George W. Cooper	917 Lindbergh Ave., Zanesville, Ohio

Geographical District Executive Committees

District	Chairman (Vice-President, AIEE)	Secretary (District Secretary)	Chairman, District Committee on Student Activities
1 North Eastern	E. W. Davis, Simplex Wire & Cable Co., 79 Sidney St., Cambridge 39, Mass.	Victor Siegfried, American Steel & Wire Co., Worcester 7, Mass.	E. R. McKee, University of Vermont, Burlington, Vt.
2 Middle Eastern	E. S. Fields, Cincinnati Gas & Electric Co., 4th & Main Sts., Cincinnati 1, Ohio	A. A. Johnson, Westinghouse Electric Corporation, East Pittsburgh, Pa.	P. X. Rice, Pennsylvania State College, State College, Pa.
3 New York City	O. E. Buckley, Bell Telephone Laboratories, Inc., 463 West St., New York 14, N. Y.	J. L. Callahan, R.C.A. Laboratories, Radio Corporation of America, 66 Broad St., New York, N. Y.	Harry Baum, College of the City of New York, 139th St. & Convent Ave., New York, N. Y.
4 Southern	Herman B. Wolf, Duke Power Company, Charlotte 1, N. C.	C. B. Galphin, 2312 Greenway, Charlotte 4, N. C.	Brinkley Barnett, University of Kentucky, Lexington, Ky.
5 Great Lakes	T. G. LeClair, Commonwealth Edison Company, 72 W. Adams St., Chicago 90, Ill.	N. C. Pearcy, Public Utility Engg. & Service Corp., 231 S. La Salle St., Chicago 4, Ill.	J. H. Kuhlmann, University of Minnesota, Minneapolis, Minn.
6 North Central	L. M. Robertson, Public Service Co. of Colorado, Denver, Colo.	H. F. Gidlund, Public Service Co. of Colorado, Denver, Colo.	O. E. Edison, University of Nebraska, Lincoln, Nebr.
7 South West	R. F. Danner, Oklahoma Gas & Electric Co., Oklahoma City 1, Okla.	W. B. Stephenson, Southwestern Bell Telephone Co., Oklahoma City 2, Okla.	C. L. Farrar, University of Oklahoma, Norman, Okla.
8 Pacific	F. F. Evenson, 600 E. Harbor St., P.O. Box 1710, San Diego, Calif.	Walter L. Bryant, U. S. Navy Electronics Laboratory, San Diego 52, Calif.	W. H. Pickering, California Institute of Technology, Pasadena, Calif.
9 North West	C. F. Terrell, Puget Sound Power & Light Co., 860 Stuart Bldg., Seattle, Wash.	C. H. Cutter, 814 Securities Building, Seattle 1, Wash.	E. W. Schilling, Montana State College, Bozeman, Mont.
10 Canada	F. L. Lawton, Aluminum Co. of Canada Ltd., 1700 Sun Life Bldg., Montreal, Que.	D. M. Farnham, Quebec Hydro-Elec. Commission, 107 Craig St. West, Montreal, Que.	

NOTE: Each District executive committee includes also the chairmen and secretaries of all Sections within the District, and the District vice-chairman of the AIEE membership committee.

Institute Representatives (continued from page 480)

American Year Book, Advisory Board
H. H. Henline

Charles A. Coffin Fellowship and Research Fund Committee
J. Elmer Housley

Committee of Apparatus Makers and Users, NRC
L. F. Adams

Committee on Standard Commodity Classification or Index
E. B. Paxton

Electrical Standards Committee, ASA
H. E. Farrer — A. G. Monteith — J. J. Pilliod
Alternates
W. P. Dobson — E. L. Moreland — E. B. Paxton

Engineering Foundation Board
L. W. Chubb — F. M. Farmer

Engineering Societies Monographs Committee
F. M. Farmer — W. I. Slichter

Engineering Societies Personnel Service, Inc.
H. H. Henline

Engineers' Council for Professional Development
M. S. Coover — Everett S. Lee — E. C. Stone

Engineers Joint Council
H. H. Henline — J. Elmer Housley — W. E. Wickenden

Harts Award Committee
M. S. Coover

Hoover Medal Board of Award
H. H. Barnes, Jr. — H. S. Osborne
John Castlereagh Parker

Industry Committee on Interior Wiring Design
M. M. Brandon — L. C. Peterman

John Fritz Medal Board of Award
Nevin E. Funk — C. A. Powel
J. Elmer Housley — W. E. Wickenden

Joint Committee for Development of Statistical Applications in Engineering and Manufacturing
W. P. Dobson

Library Board, United Engineering Trustees, Inc.
N. S. Hibshman — G. L. Knight
H. H. Henline, *ex officio* — H. M. Turner

Marston Medal Board of Award
Harry B. Gear

National Bureau of Engineering Registration, Advisory Board
T. G. LeClair

Institute Representatives (cont'd)

National Fire Protection Association, Electrical Committee
L. F. Adams — W. Ralph Smith, *alternate*

National Fire Waste Council
L. F. Adams — Wills Maclachlan

National Research Council, Division of Engineering and Industrial Research
W. B. Kouwenhoven

National Technological Advisory Committee
John Castlereagh Parker

Quarterly of Applied Mathematics
J. G. Brainerd

Radio Technical Planning Board
H. A. Affel

United Engineering Trustees, Inc.
W. H. Harrison — C. R. Jones — Everett S. Lee

United States National Committee of the International Commission on Illumination
W. Barker — Robin Beach — S. G. Hibben

United States National Committee of the International Electrotechnical Commission
H. E. Farrer — A. C. Monteith — J. J. Pilliod
Alternates
W. P. Dobson — E. L. Moreland — E. B. Paxton

Washington Award Commission
M. S. Coover — H. B. Gear

World Power Conference, Executive Committee of United States National Committee
J. Elmer Housley

Student Branches of the Institute

Name and Location	District	Counselor (Member of Faculty)
Akron, University of, Akron, Ohio	2	A. J. Fairburn
Alabama Polytechnic Institute, Auburn	4	
Alabama, University of, University	4	William J. Miller
Alberta, University of, Edmonton, Canada	10	R. E. Phillips
Arizona, University of, Tucson	8	J. C. Clark
Arkansas, University of, Fayetteville	7	A. S. Brown
British Columbia, University of, Vancouver, Canada	10	W. B. Coulthard
Brooklyn, Polytechnic Inst. of, Brooklyn, N. Y. (Day)	3	F. A. Wahlers
(Evening)	3	Anthony Giordana
Brown University, Providence, R. I.	1	F. N. Tompkins
Bucknell University, Lewisburg, Pa.	2	George Irland
California Institute of Technology, Pasadena	8	W. H. Pickering
California, University of, Berkeley	8	P. L. Morton
Carnegie Institute of Technology, Pittsburgh, Pa.	2	D. W. VerPlanck
Case School of Applied Science, Cleveland, Ohio	2	P. L. Hoover
Catholic University of America, Washington, D. C.	2	T. J. MacKavanagh
Cincinnati, University of, Cincinnati, Ohio	2	A. C. Herweh
Clarkson College of Technology, Potsdam, N. Y.	1	Alfred R. Powers
Clemson Agricultural College, Clemson, S. C.	4	F. T. Tingley
Colorado State Coll. of A. & M. Arts, Ft. Collins	6	C. F. Chinburg
Colorado, University of, Boulder, Colo.	6	Platt Wicks
Columbia University, New York, N. Y.	3	W. A. LaPierre
Connecticut, University of, Storrs	1	G. S. Timoshenko
Cooper Union, New York, N. Y.	3	Norman L. Towle
Cornell University, Ithaca, N. Y.	1	B. K. Northrop
Delaware, University of, Newark	2	Milton G. Young
Denver, University of, Denver, Colo.	6	Fred H. McClain
Detroit, University of, Detroit, Mich.	5	H. O. Warner
Drexel Institute of Technology, Philadelphia, Pa.	2	F. C. Powell
Duke University, Durham, N. C.	4	K. B. MacKichan
Florida, University of, Jacksonville	4	Edward F. Smith
George Washington University, Washington, D. C.	2	Milton K. Akers
Georgia School of Technology, Atlanta, Ga.	4	H. B. Duling
Harvard University, Cambridge, Mass.	1	John P. Newton
Idaho, University of, Moscow	9	J. Hugo Johnson
Illinois Institute of Technology, Chicago	5	E. T. B. Gross
Illinois, University of, Urbana	5	E. A. Reid
Iowa State College, Ames	5	B. S. Willis
Iowa, University of, Iowa City	5	E. B. Kurtz
Johns Hopkins University, Baltimore, Md.	2	F. Hamburger, Jr.
Kansas State College, Manhattan	7	Joe E. Ward
Kansas, University of, Lawrence	7	David D. Robb
Kentucky, University of, Lexington	4	Brinkley Barnett
Lafayette College, Easton, Pa.	2	Morland King
Lehigh University, Bethlehem, Pa.	2	J. E. Beaver
Louisiana State University, Baton Rouge	4	A. K. Ramsey
Louisville, University of, Louisville, Ky.	4	M. C. Northrup
Maine, University of, Orono	1	W. J. Creamer
Manhattan College, New York, N. Y.	3	Robert T. Weil
Marquette University, Milwaukee, Wis.	5	E. W. Kane
Maryland, University of, College Park	2	L. J. Hodgins
Massachusetts Inst. of Technology, Cambridge	1	D. P. Severance
Mich. College of Mining & Tech., Houghton	5	G. W. Swenson
Michigan State College, East Lansing	5	J. A. Strelzoff
Michigan, University of, Ann Arbor	5	J. S. Gault
Milwaukee School of Engg., Milwaukee, Wis.	5	E. L. Wiedner
Minnesota, University of, Minneapolis	5	J. H. Kuhlmann
Mississippi State College, State College	4	Harry C. Simrall
Missouri School of Mines & Metallurgy, Rolla	7	I. H. Lovett
Missouri, University of, Columbia	7	Clifford M. Wallis
Montana State College, Bozeman	9	G. Dale Scheckels
Nebraska, University of, Lincoln	6	O. E. Edison
Total Branches	126	

Name and Location	District	Counselor (Member of Faculty)
Nevada, University of, Reno	8	S. G. Palmer
Newark College of Engineering, Newark, N. J.	3	William Jordan
New Hampshire, University of, Durham, N. H.	1	W. B. Nulsen
New Mexico State College, State College	7	Harold A. Brown
New Mexico, University of, Albuquerque	7	R. W. Tapy
New York, Coll. of the City of, New York, N. Y.	3	Harry Baum
New York University, New York	3	Charles F. Rehberg
North Carolina State College, Raleigh	4	C. G. Brennecke
North Dakota State Agricultural College, Fargo	5	Harry S. Dixon
North Dakota, University of, Grand Forks	5	C. W. Rook
Northeastern University, Boston, Mass.	1	Roland G. Porter
Northwestern University, Evanston, Ill.	5	R. Beam
Norwich University, Northfield, Vt.	1	F. A. Spencer
Notre Dame, University of, Notre Dame, Ind.	5	L. F. Stauder
Ohio Northern University, Ada	2	
Ohio State University, Columbus	2	
Ohio University, Athens	2	
Oklahoma A. & M. College, Stillwater	7	Albrecht Naeter
Oklahoma, University of, Norman	7	C. L. Farrar
Oregon State College, Corvallis	9	A. L. Albert
Pennsylvania State College, State College	2	P. X. Rice
Pennsylvania, University of, Philadelphia	2	S. Reid Warren, Jr.
Pittsburgh, University of, Pittsburgh, Pa.	2	R. C. Gorham
Pratt Institute, Brooklyn, N. Y.	3	Donald H. Wright
Princeton University, Princeton, N. J.	2	J. E. Paul
Puerto Rico, University of, Mayaguez, P. R.	3	Miguel Wiewall, Jr.
Purdue University, Lafayette, Ind.	5	R. B. Marshall
Rensselaer Polytechnic Institute, Troy, N. Y.	1	Emerson D. Broadwel
Rhode Island State College, Kingston	1	
Rice Institute, Houston, Tex.	7	M. V. McEnamy
Rose Polytechnic Institute, Terre Haute, Ind.	5	C. C. Knipmeyer
Rutgers, University, New Brunswick, N. J.	3	P. S. Creager
Santa Clara, Univ. of, Santa Clara, Calif.	8	W. J. Warren
South Carolina, University of, Columbia	4	Samuel Litman
South Dakota State College, Brookings	5	W. H. Gamble
South Dakota State School of M. & T., Rapid City	6	J. O. Kammerman
Southern California, Univ. of, Los Angeles	8	P. S. Biegler
Southern Methodist Univ., Dallas, Tex.	7	R. L. Bessels, Jr.
Stanford Univ., Stanford University, Calif.	8	W. G. Hoover
Stevens Inst. of Technology, Hoboken, N. J.	3	
Swarthmore College, Swarthmore, Pa.	2	J. D. McCrumm
Syracuse University, Syracuse, N. Y.	1	Leroy Mullin
Tennessee, University of, Knoxville	4	W. O. Leffell
Texas, A. & M. College of, College Station	7	N. F. Rode
Texas Technological College, Lubbock	7	
Texas, University of, Austin	7	A. J. McCrocklin, Jr.
Toronto, University of, Toronto, Ont., Can.	10	L. S. Lauchland
Tufts College, Medford, Mass.	1	A. H. Howell
Tulane University, New Orleans, La.	4	M. G. Zervigon
Union College, Schenectady, N. Y.	1	H. W. Bibber
Utah, University of, Salt Lake City	9	O. C. Haycock
Vanderbilt University, Nashville, Tenn.	4	S. R. Schealer
Vermont, University of, Burlington	1	E. R. McKee
Villanova College, Villanova, Pa.	2	Harry S. Bueche
Virginia Military Institute, Lexington	4	J. S. Jamison
Virginia Polytechnic Institute, Blacksburg	4	Claudius Lee
Virginia, University of, Charlottesville	4	L. R. Quarles
Washington, State College of, Pullman	9	H. F. Lickey
Washington, University of, Seattle	9	Vinson L. Palmer
Washington University, St. Louis, Mo.	7	D. A. Fischer
West Virginia University, Morgantown	2	A. H. Forman
Wisconsin, University of, Madison	5	G. F. Tracy
Worcester Poly. Institute, Worcester, Mass.	1	D. C. Alexander
Wyoming, University of, Laramie	6	R. O. Truehlood
Yale University, New Haven, Conn.	1	A. G. Conrad

OF CURRENT INTEREST

Electric Facilities Aid United Nations at Lake Success

The temporary quarters of the United Nations organization at Lake Success, N. Y., were used for the first time when the Security Council met on August 28, 1946. Early in July the Sperry Gyroscope Company had vacated a 650 by 650 foot portion of their wartime plant as well as their administration building at Lake Success on Long Island. Extensive alterations had been effected in the next 46 days. The entire electrical installation was planned, engineered, and supervised by Voorhees, Walker, Foley, and Smith, architects and engineers of New York, N. Y.

There are two main council chambers, each approximately 80 by 80 feet. One chamber, used by the Security Council, seats 18 delegates, 16 interpreters, 214 press representatives, and 515 members of the general audience. The other chamber, used by the Social and Economic Council, is equipped to seat a total of 750 people. Supplementing these chambers are four large conference rooms, each seating 55 delegates, 12 interpreters, and an audience of 180. Behind these main council chambers and conference rooms office space is provided for the various United Nations functions as well as the press services.

Each council chamber has been designed to have a general illumination of 58 foot-candles at the center of the room, which tapers to 35 foot-candles at the edges. Figure 1 shows the soft illumination and interesting patterns on the ceiling which are provided by continuously louvered fluorescent units suspended below the acoustically treated ceiling. A total of 24,000 watts illumination is provided in each chamber. This gives an average of 3.7 watts per square foot under the louvered section. The low-brightness 40-watt 5-foot 4,500-degree white fluorescent tubes are controlled by instant-start 2-lamp high-power-factor ballasts. To protect the critical and expensive sound system one radio interference filter is installed for each pair of lamp ballasts. Most of the light is concentrated in a downward direction by the louvers. They also provide 45-degree cutoff of direct vision of the tubes.

The removable louver frames are made of 14-gauge aluminum. Each is 66 inches long, 30 inches wide, and weighs less than 30 pounds. This arrangement greatly facilitates maintenance and replacement of lamps. Exact alignment of the centered louver frames is required to give the desired neat and precise pattern and was one of the greatest problems encountered during the construction period. These council chamber ceilings are reputed to be the largest continuously louvered ceilings in existence.

Directly above the main conference table supplementary lighting is provided by 12 1,000-watt floodlights mounted in the ceiling and controlled by autotransformer type dimmers. These lights are visible in Figure 1.

Available in each council chamber are 14 radio booths, one control room, 2 photography booths, 3 motion picture booths (one of which is equipped for sound), and one television booth. Twelve-circuit lighting panels are provided to service the felctypewriters and other machinery required by the various press services. This power supply is an adaptation of the original power plug-in system installed when the area was used for manufacturing purposes.

The sound system provides an individual microphone for each delegate. Two large loud-speakers in the ceiling service the main chamber. These are supplemented by several low-level loud-speakers located at various points through the elevated press section. A regular and an emergency bus from the main amplifier room provide for sound distribution to each radio, television, and motion picture booth.

The main council chambers and the conference rooms are treated acoustically on both the ceilings and walls.

Eight 500-kva Westinghouse unit substations originally used by the Sperry company have been taken over by the United Nations. The load on these units now ranges from 52 to 80 per cent of their total capacity, thus providing a margin for future expansion and development. Westinghouse plug-in "busways" originally located in each of the 40- by 80-foot bays of the manufacturing plant were moved and concentrated at monitor locations from which plug-in circuits are taken to various lighting panels for local control of illumination and local power circuits.

The air conditioning of the original Sperry plant was modified only to accommodate the subdivisions of the council chambers, offices, and conference rooms. Electrostatic precipitators clean and filter the air used in the air-conditioning system.

Wide World Photo

Figure 1. Temporary quarters of the security council at Lake Success

The loud-speakers and ventilation ducts are visible in the louver ceiling. A low-level loud-speaker located in the press section is visible in the upper section of the picture

Record Train Radio Contact. What is believed to be a long-distance record for radiotelephone communications between a fixed station and a train was achieved during recent tests by the Nickel Plate Road. Contact was maintained between a low power fixed station at a height of 600 feet in Cleveland, Ohio, and a radio-equipped train up to a point opposite the Bellevue, Ohio, yard office, a distance of 63 miles.

UNESCO to Work for World-Wide Scientific Unity

The 79th Congress of the United States before adjourning in July enacted a Joint Resolution authorizing the President to accept membership for the United States in the United Nations Education, Scientific, and Cultural Organization. In his statement of acceptance, the President declared: "The Government of the United States will work with and through UNESCO to the end that the minds of all people may be freed from ignorance, prejudice, suspicion, and fear, and that men may be educated for justice, liberty, and peace."

In addition to authorizing membership in UNESCO, the Joint Resolution provides for the organization of a National Commission on Education, Scientific and Cultural Co-operation, which will advise the Government and serve as a link with national private organizations in matters relating to UNESCO. The commission will have 100 members, of whom 60 will be selected by each of 60 national organizations interested in education, science, and cultural matters, and 40 will be persons selected by the Department of State. Fifty of the organizations which will select representatives on the National Commission will be named soon by the Department of State; the remaining ten organizations will be chosen later by the National Commission itself.

The constitution of UNESCO was drafted by a Conference of Allied Ministers of Education following the San Francisco Conference and was signed by 43 United Nations at a conference held in London, November 1–16, 1945.

Besides the United States 14 nations now have endorsed UNESCO. In the hope that the UNESCO constitution will receive endorsement from the minimum of 20 governments necessary to put it into operation, the Department of State participated in the meetings of the Preparatory Commission, most recent of which was held July 5–12 in London, and is planning to participate in the first meeting of the General Conference, set for November in Paris.

Assisting the Department of State in connection with the work of the Preparatory Commission was an informal advisory committee of scientists. The science advisers found more problems than they solved. Since UNESCO does not in fact exist, its organization, administration, and financial structure and resources are problematical. Under these conditions planning is difficult and must be flexible. Nevertheless, the committee set for itself two major tasks, one of which is essentially complete: It endeavored to formulate scientific projects with which UNESCO may deal profitably, and it submitted a list of suggestions to be considered by the Preparatory Commission for the agenda of the Paris meeting in November. It also will attempt to evolve machinery through which American scientists may take a direct and active part in the scientific work of UNESCO, for the latter, to be successful, must command the interest and confidence of every professional group and, ideally, of every individual scientist.

The suggestions regarding a scientific program for UNESCO were transmitted by Doctor W. Albert Noyes, Jr., chairman of the department of chemistry of the University of Rochester, N. Y., who, as the committee's representative, attended a meeting of the Subcommittee on Science of UNESCO's Preparatory Commission in London on May 31 and June 1. Doctor Noyes reported that there was a strong desire on the part of the nations represented to make UNESCO a successful organization and "to give it a program which will capture the imagination as being worth while for the long-range future." At the London meeting, projects were discussed at length, and those to which highest priority has been given because of their significance and immediacy are:

1. Facilitate the exchange of personnel, of apparatus, and of information particularly by providing foreign exchange, arranging for diplomatic passports or visas when feasible, and by providing information on locations of scientific centers, and the like.

2. Facilitate the transfer of funds when such transfer is essential to international co-operation in science.

3. Co-operate with existing international organizations, particularly international scientific unions.

4. Aid wherever possible the furnishing of apparatus and of personnel to needy countries, and particularly to start a survey of such needs.

5. Provide scholarships, fellowships, and other financial aid for exchanges of personnel of various types among the co-operating countries.

UNESCO is setting for itself a program of rehabilitation and co-operation which will restore and extend the interrupted flow of scientific research. Not only does it face the task of resuscitating scientific endeavor in nations that must rebuild from their very foundations, but also of persuading national groups to co-ordinate their efforts toward common ends. It pledges co-operation with existing agencies, notably the international scientific unions, and it thus establishes itself as a co-ordinating and supplemental agency rather than as a competing entity. Not the least of its problems is that of co-ordinating its activities with the programs of other United Nations organizations, notably those dealing with agriculture and with public health, both of which deal not alone with applied science, but with fundamental aspects of biology and chemistry as well.

Exposition Concurrent With AIEE Winter Meeting

An electrical engineering exposition will be held January 27–31, 1947, at the 71st Regiment Armory, New York, N. Y., concurrently with the AIEE winter meeting. The exposition, which will feature newest developments in electrical equipment for the generation, transmission, distribution, and utilization of electric energy, is designed to be of special benefit to engineers and operating men who are responsible for the design, construction, and operation of large electric installations. Attendance will be controlled through invitations and registration; the general public will not be admitted. Originally announced for January 1941, the exposition was postponed because of the war. C. F. Roth is

Moving Pictures Now Research Tool

The operator at the left is taking moving pictures at 4,500 feet per second of a cabinet to house electric apparatus as it undergoes a 5,500 foot-pound impact test at the Westinghouse Electric Corporation, Pittsburgh, Pa. The 5,000-pound hammer in the rear has been raised to the exact height to produce the desired impact when it swings through an arc and strikes the underside of the platform on which the cabinet is bolted. When these films are projected at 16 feet per second, failures are easily analyzed

president of the company and E. K. Stevens is manager of the exposition. Other members of the advisory committee are:

J. T. Barron (F '27) vice-president, Public Service Electric and Gas Company; Walter S. Finlay, Jr. (F '21) vice-president, J. G. White Engineering Corporation; E. S. Fitz (M '32) general manager of the electrical department, Virginia Electric and Power Company; N. E. Funk (F '34) vice-president, Philadelphia Electric Company; C. W. Leihy (M '38) of *Electric Light and Power*; A. L. Penniman, Jr. (F '43) general superintendent of electric operations, Consolidated Gas Electric Light and Power Company of Baltimore; W. A. Perry (M '38) assistant to the general superintendent, Inland Steel Company; R. C. Roe (F '33) Burns and Roe, Inc; R. W. Wilbraham (F '45) chief electrical engineer, United Engineers and Constructors, Inc.; and S. B. Williams (M '37) of *Electrical World*.

Underwriters' Consider Use of Aluminum Conductors

Because present shortages in copper supply have stimulated proposals for the use of aluminum wire as conductors for insulated wires and cables as covered by sections 1109 and 3107 of the National Electrical Code, the Underwriters' Laboratories, Inc., has prepared the following list of the special considerations which the use of aluminum demands. The code, it is pointed out, assumes that conductors will be of copper.

Conductivity. The value of 84 per cent of that of copper specified in section 3107 of the code may be accepted.

Conductor Size. For the conductors of branch circuits that are fused at 15 amperes, number 12 American wire gauge aluminum wire should be used, instead of number 14. (On this account larger sizes of raceways may be necessary for the same number of conductors.)

Many appliances and devices with binding screw type terminals do not accommodate readily a number 12 Browne and Sharp gauge wire, and, obviously, for branch circuits of greater current ratings, larger aluminum conductors will not be accommodated by them.

Electrolytic or Galvanic Effect. Most appliances and devices have copper or brass terminals for wire connections. Because of the electrolytic effect, aluminum conductors secured to such terminals may be severely or completely corroded by such contact between these dissimilar metals. There is some field experience demonstrating this, and laboratory tests confirm the possibility. This effect is a fundamental property because of the positions of copper, its alloys, and of aluminum in the electromotive scale.

Moist atmospheres act as electrolytes, especially near the seacoast or in inland industrial areas. Several of the occupancies listed in section 3003 of the code, wherein corrosion may be expected, involve conditions favoring the electrolytic effect.

At equipment terminals that do not employ binding screws, electrical connection generally is made by soldering lugs or by pressure connectors. At present such terminal fittings are not generally available except in copper or brass. In moist atmospheres the electrolytic effect may develop in due time with connections of these types, unless inserts of a neutral metal such as zinc, or other special methods, are used. The mechanical and electrical reliability of such connections depend upon practices and workmanship not as yet generally employed. Dressing connections with coatings to exclude air from contact areas may not be a permanent measure.

Soldering. Suitable solders and soldering fluxes for joints between aluminum conductors or between such conductors and terminal fittings of other metals are not commonly available, and knowledge of the use of those that are available is limited.

Voltage Drop. Because of lower conductivity the effect of voltage drop must have special consideration in layouts of wiring and loads.

Melting Point. The lower melting point of aluminum will produce different effects under short-circuit conditions. Very likely burnouts in raceways and fittings of other metals from accidental grounds will be less frequent and less severe.

In delineating its position, the Laboratories declared that these conditions might justify deferring recognition of building wires with aluminum conductors. However, it stated that certain phases of the present conditions approach the status of an emergency which may warrant special action by all concerned, including inspection authorities having jurisdiction. However it warns that the possible appearances of some of the phenomena discussed, perhaps long after the emergency has passed, should not be ignored.

This dubious view is qualified by the statement that "it seems clear that in many areas and in various premises in perhaps other areas, conditions likely to favor corrosion troubles because of this emergency substitution never may be present. Perhaps the sum total of premises where the substitution will not add to hazards to life and property greatly exceeds that of those where trouble may be anticipated."

In conclusion the Laboratories announce that its Electrical Council and manufacturers of building wires have been informed that effective September 1, inspected rubber-covered wire labels may be used on number 12 conductors and larger.

Engineering Books Presented to China

Doctor C. D. Shiah (left), representative of the National Resources Commission of China, thanking Stewart E. Reimal of the International Relations Committee of Engineers Joint Council for shipment of more than 4,000 items of engineering literature (EE, July 1946, pp 360-1)

Facsimile Newspaper Trial Set for Early Next Year

That limited transmission of facsimile newspapers in at least a dozen cities is planned for early in 1947 was revealed recently by the General Electric Company.

The company announced that it had received an order for transmitters and receivers from John V. L. Hogan (M '20) president of Radio Inventions, Inc., on behalf of Broadcasters Faximile Analysis, an organization of 22 broadcasters and newspapers. The equipment to be manufactured was developed for this group by Radio Inventions and demonstrated to the press last spring (*EE, June '45, p 292*).

Although it is not certain which newspapers and radio stations will experiment immediately with the medium, the follow-

ing have ordered varying amounts of equipment:

Station WOR, New York; WQXR, the *New York Times* station; the *Baltimore News Post*; the *Washington* (D. C.) *Post*; the *Boston Globe*; WGN, the *Chicago Tribune* station; WNBH, New Bedford, Mass., the *Standard Times* station; WDRC, Hartford; KMBC, Kansas City; the *Toronto Globe and Mail*; the Columbia Broadcasting System; the *St. Louis Star-Times* station; KYW, Philadelphia; WFIL, Philadelphia; WOKO, Albany; the *Detroit Free Press*; the *Akron Beacon Journal*; and the *Miami Herald*.

Egyptian Commission Tours U. S. and Canada

In connection with its pending decision on bids for the building of a hydroelectric station at the Aswan Dam on the Nile River, the Hydroelectric Power Commission of the Egyptian Government visited engineering companies and major hydroelectric power stations in the United States and Canada during a trip lasting from August 5 to September 10.

Invitations for tenders on the Nile project were circulated in January 1946 and were extended to firms in Great Britain, the United States, Switzerland, France, Sweden, and Russia. The closing date for the submission of tenders is October 31. Cost of building the station has been estimated at $40,000,000, excluding the transmission. Output to be obtained from the project will be 280,000 kw, of which 100,000 kw will be available throughout the year and the remaining 180,000 kw for nine months of the year.

Doctor Abdel Aziz Bey Ahmed, chairman of the commission, was of the opinion that modern American excavation equipment would be especially suited to another project, the Quattara Hydroelectric Scheme, currently being studied by the commission. The commission is considering making a cut from the Mediterranean to the Quattara depression which lies west of the Nile delta at 450 feet below sea level. Sea water flowing into the depression as a result could be used to generate power.

Other members of the commission are: Mustafa Bey Fathy, Undersecretary of the Ministry of Public Works; A. Khairy Bey, Director of Reservoirs, Ministry of Public Works; and Geoffrey F. Kennedy, partner in the London firm of Kennedy and Donkin, consulting engineers.

Radiotelephone Aids Train Operation. That the use of radio on freight trains contributes to greater efficiency of operation is indicated by a series of tests conducted by the Western Electric Company in cooperation with the Northern Pacific Railway Company. The tests were made on runs between Seattle and Yakima, Wash., a distance of about 145 miles and between Seattle and Portland, Oreg., a distance of about 180 miles. Besides savings in time, more satisfactory operations were assured in pulling into sidings to let other trains pass, ascertaining whether or not the rear end of the train was completely on the siding, picking up additional cars, picking up trainmen, preparing for cut-in of helper engines, switching operations, and train-to-yard contacts. The equipment used consisted of a radio transmitter and receiver, handset type microphone with push-to-talk button, loud-speakers and control unit, power supply comprising a generator and inverter, and a quarter wave vertical antenna with ground plane. The equipment was installed in two Diesel-electric locomotives and in two steam locomotives and in an engine house for wayside station testing.

New Superconductor Reported. Development of metal ammonia solutions, which, after rapid freezing, are superconductive at temperatures as high as minus 85 degrees centigrade has been reported by Doctor Richard A. Ogg, Jr., of Stanford University. The materials are liquid ammonia solutions of alkali metals (such as lithium, sodium, and potassium) and alkaline earth metals (barium, calcium, and strontium). As a clue to the mechanism of superconductivity, it has been noted that in these solutions two electrons will hold together without a nucleus, whereas ordinarily two atomic nuclei would be held together by two electrons.

Army's New Flight Trainer. A new and advanced type of electronic flight trainer for instrument flight and radio navigation instruction has been developed for the Army Air Forces by Curtiss-Wright Corporation. As the trainer easily can be adapted for instruction in flying any model airplane, it is expected that in more general use it will reduce greatly the cost to airlines of training pilots for operation of new type airplanes. In appearance the Dehmel AT-6 trainers purchased by the AAF resemble a single-seat airplane fuselage, minus wings and tail section. The enclosed fuselage contains the pilot's seat, aircraft controls, and lighted instrument panel. An amplifier provides variable engine noises such as occur in flight. It is unnecessary to turn or bank the fuselage, as an electronic computing system, similar to those in electronic gun directors, translates the operation of the rudder, throttle, elevator, and other controls into the instrument readings that would guide a pilot in actual flight.

EDUCATION . . .

Plea for Teachers' Pay Increase. American youth cannot be properly educated for an atomic age until high school science teachers are paid higher salaries than janitors and milkmen, according to a recent statement by Doctor Paul E. Klopsteg, chairman of the American Institute of Physics and director of the Technological Institute of Northwestern University. "The discrepancy between teachers' salaries and incomes in other occupations is much wider in the United States than in other countries," he added. "This means that there is less incentive, relatively, for the best brains to enter teaching." Recent surveys, Doctor Klopsteg said, have shown that the average teacher salary is about $1,500 a year, and most high school teachers receive less than $2,000. In conclusion Doctor Klopsteg stressed the need for good teaching at the high school level as fundamental in inspiring students to undertake scientific careers and in instilling a familiarity with science basic to modern good citizenship.

Iowa Offers Course in Quality Control. An intensive ten-day course in quality control by statistical methods is being offered October 15–25 by the University of Iowa, Iowa City. A follow-up program in which two two-day clinics will be held with the industrial representatives to discuss common problems and to obtain additional information is planned. This is the fourth such course given by the university since October 1944. It is designed for executives and persons in an advisory position where the knowledge gained can be applied immediately. The course consists of a series of conferences, lectures, and laboratory periods lasting from 8:30 a.m. to 5 p.m. each day except Sunday. General lectures will be given to the entire group. However, to facilitate the discussion of specific problems and the working of laboratory exercises, the trainees will be divided into small sections under the direct supervision of an instructor. The tuition for the course including books and supplies is $100. Trainees will be expected to provide for their own living expenses and transportation. Additional details may be secured from Professor Earle L. Waterman, College of Engineering, State University of Iowa.

New Engineering Physics Degree. A department of engineering physics with a five-year curriculum leading to the degree of bachelor of engineering physics has been started at Cornell University with the 1946 fall term. The department is designed to meet industry's demand for men with broad training in engineering and physics to work in industrial research and development. Students will have wide latitude in selecting specialties within the curriculum, such as atomic physics, optics, electronics and ionics, ultrahigh frequencies, elasticity and stress analysis, and aerodynamics.

Education Quarterly at Iowa. Announcement has been made by the University of Iowa of the forthcoming publication of a quarterly devoted to "expression of the newest thought in the field of general edu-

cation, from the secondary school to the graduate or professional unit of the university." Dean Earl James McGrath of the college of liberal arts of the University of Iowa is the editor of the new *Journal of General Education*, which will be issued October 1, January 1, April 1, and July 1. Subscription rates are $2 per year and the business address is University Hall, Iowa City, Iowa. The board of editorial consultants consists of Byron S. Hollinshead, B. Lamar Johnson, Lennox Grey, W. H. Cowley, Raphael Demos, W. E. Wickenden (F '39), Doak S. Campbell, Lewis Mumford, William P. Tolley, T. R. McConnell, Robert J. Havighurst, and John W. Harbeson.

INDUSTRY.....

Brown Boveri Affiliate Formed. Formation of the Brown Boveri Corporation under the laws of New York State as an affiliate of Brown, Boveri and Company, Ltd., Baden, Switzerland, recently was announced. The new corporation, headquarters of which are in New York, N. Y., expects to intensify dissemination of data and information on new Brown Boveri products and to furnish assistance in solving operating and repair problems where needed. Paul R. Sidler (A '31) formerly resident engineer in New York for the Swiss company, is president of the new company.

Scrap Shortage Slows Production. A campaign to impress industry with the urgency for cleaning scrap metals out of industrial establishments is being conducted by the American Iron and Steel Institute. Recently 25 to 30 open hearth steel furnaces in which scrap normally makes up 50 per cent of the charge have been shut down, receipts of scrap are declining, and inventories at mills are near the vanishing point. As a result industrial production in general is threatened.

Underwater Search for Oil by Radar. The Standard Oil Company, Ltd., a subsidiary of the Standard Oil Company of New Jersey, soon will start a search for oil under the 2,000 square miles of water in the northwestern Bahamas with the aid of diving chambers equipped with radar. In much of the area to be prospected the ocean is less than 20 feet deep.

JOINT ACTIVITIES

Milwaukee Engineers Open New Headquarters

A week of events celebrating the opening of the new headquarters of the Engineers' Society of Milwaukee culminated in a banquet on September 21 attended by 1,600 engineers and friends. Principal speaker at the dinner was Doctor Charles F. Kettering (F '14) vice-president in charge of research for General Motors Corporation, whose topic was "The Challenge and Opportunities of Tomorrow."

Plans for the new headquarters were commenced in 1944 with the purchase of the mansion of Frederick Pabst, nationally known brewer. A subsequent campaign raised $100,000 from more than 100 contributing firms to defray the cost of remodeling and equipping the building. Although the architectural style of the original structure has been retained, such improvements as indirect lighting and acoustical ceiling have been added. The building now contains three small auditoriums, two of which may be expanded to one large hall by means of a sliding wall, a library and reading room, offices, committee meeting rooms, lounges, two dining rooms, and recreation and powder rooms for women.

The Milwaukee Society has a membership of 1,366 and affiliated with it are the local sections of the following national societies: the AIEE, the American Society of Mechanical Engineers, the American Society of Civil Engineers, the American Society of Refrigerating Engineers, the American Society of Heating and Ventilating Engineers, the Institute of Radio Engineers, and the Illuminating Engineering Society.

Officers of local affiliated societies attending a recent board meeting of the Engineers' Society of Milwaukee. Seated left to right are: L. W. Butler, IRE; F. J. Van Zeeland (M '44) AIEE; E. T. Sherwood (M '44) IRE; Walther Richter (F '42) AIEE; Charles W. Yoder, ASCE; Lloyd D. Knapp, ASCE; Edward W. Schmidtman, ASCE; Del C. Albright, ASRE; Standing left to right are: Phil Laeser, IRE; Ernest F. Vilter, ASRE; Edwin H. Cordes, IRE; Herbert F. Wareing, IRE

Artist's sketch of the new headquarters of the Engineers' Society of Milwaukee

OTHER SOCIETIES •

Symposium on Fluorine Sponsored by Chemical Society

How wartime research completed the previously unsolved problem of controlling fluorine gas for practical purposes was disclosed in great detail at a symposium conducted September 11, 12, and 13 in connection with the 110th national meeting of the American Chemical Society in Chicago, Ill.

The 51 papers presented at the symposium described the wartime scientific and technological advancement in the generation of fluorine and the preparation of fluorine compounds, especially fluorcarbons, or organic compounds composed of only carbon and fluorine. Small scale production and handling of fluorine also were discussed.

As much of the research was carried out as part of the atomic bomb project, some of the findings still are classified as secret by the Army. The development of anhydrous hydrofluoric acid as a catalyst made possible the production of the huge quantities of high octane aviation gasoline for war use.

It was pointed out by Professor Earl T. McBee of Purdue University, who presided at the symposium, that before the war fluorine was generated in gram quantities with difficulty, while it is now available on a large scale. The technology has advanced so far, according to Professor McBee, that fluorcarbons, extremely stable noninflammable substances which prior to the war were a laboratory curiosity, now may be made commercially.

Among the suggested benefits from the conquest of fluorine are: improved plastics, anesthetics, insecticides, fungicides, fumigants, germicides, fire extinguishers, fireproofing materials, and weed killers. A lubricating oil, so stable it will permit construction of engines hitherto impossible because no known lubricant could withstand their pressure and friction, also has been predicted. A gas already developed, but requiring elemental fluorine for its production, is expected to be an almost perfect insulator for high voltage electricity.

Farm Electrification Conference. A National Farm Electrification Conference with the objective of bringing "together in conference individuals and groups interested in raising farm living standards and reducing farm production costs by increasing the profitable uses of electricity on farms" will be held November 7 and 8, 1946, in the Sherman Hotel, Chicago, Ill. The conference is sponsored by the National Electrical Manufacturers Association, the National Electrical Wholesalers Association, the Edison Electric Institute, the American Society of Agricultural Engineers, Agricultural Editors, the National Grange, and the American Society of Mechanical Engineers. Chairman of the attendance and advance registration committee is Frank E. Watts, 420 Lexington Avenue, New York 17, N. Y.

ASME Elects New Officers. Election of officers for 1947 has been announced by the American Society of Mechanical Engineers. The new officers are:

President—Eugene W. O'Brien (M '37) vice-president, W. R. C. Smith Publishing Company, Atlanta, Ga.

Vice-Presidents—Alton C. Chick, A. R. Mumford, E. E. Williams, T. S. McEwan, and Linn Helander.

Directors at Large—F. S. Blackall, Jr.; B. V. E. Nordberg; L. F. Moody; and W. A. Carter.

Lead Makes Infrared Rays Visible. Infrared rays are made visible by the presence of lead in a phosphor, Doctor Gorton R. Fonda of the General Electric Company reported in a recent paper in the *Journal* of the Optical Society of America. The discovery may point the way to new equipment with which to see in the dark similar to the "sniperscope" and snooperscope" developed during the war. Doctor Fonda obtained his results with zinc sulfide provided it contained a fraction of a per cent of lead. Preliminary exposure of the phosphor to ultraviolet rays sends electrons from their normal orbits to higher states. With phosphorescence their return to a normal state is delayed until they are released by infrared rays. A light, green in color, is given off in this process.

Future Meetings of Other Societies

American Society of Tool Engineers. Semiannual national convention, October 10–12, 1946, Pittsburgh, Pa.

American Welding Society. Annual meeting, November 17–22, 1946, Atlantic City, N. J.

Electrochemical Society. Fall meeting, October 16–19, 1946, Toronto, Ontario, Canada.

Iron and Steel Exposition. October 1–4, 1946, Cleveland, Ohio.

National Electrical Contractors Association. Annual meeting, October 14–18, 1946, Atlantic City, N. J.

National Electrical Manufacturers Association. Annual meeting, October 28–November 1, 1946, Atlantic City, N. J.

National Electronics Conference. October 3–5, 1946, Chicago, Ill.

National Exposition of Power and Mechanical Engineering. December 2–7, 1946, New York, N. Y.

National Electronic Radio and Television Exposition. First annual, October 14–19, 1946, New York, N. Y.

National Research Council. Conference on Electrical Insulation, November 7–9, 1946, Johns Hopkins University, Baltimore, Md.

Refrigeration Equipment Manufacturers Association. Fourth refrigeration and air conditioning exposition, October 29–November 1, 1946, Cleveland, Ohio.

Society of Motion Picture Engineers. 60th semiannual convention, October 21–25, 1946, Hollywood, Calif.

Television Broadcasters Association, Inc. Second conference and exhibition, October 10–11, 1946, New York, N. Y.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

Engineer-to-Be Looks Ahead

To the Editor:

And lo, a child shall lead them! Reading over the following composition gave me much material for thought. If our son, brought up to believe that each one of us is given a special talent which must be developed for the good of his fellow man, has thoughts about reaction motors and spaceships of terrifying destructive powers, how about similar dreamers who are not imbued with the thought of using that power for good?

When our son—who wrote this as a composition for his English class in high school on his 17th birthday—was 13, he badgered his engineer father to let him attend a series of lectures on nuclear physics given by an engineer from Bell Telephone Laboratories. He would rush home, change into his best clothes, dash for the citybound bus, and meet his dad for dinner near the Engineering Societies Building. He and his Dad would discuss the lectures like contemporaries.

Your magazine is pounced on immediately, when it arrives each month. And our Robert is deep in "experiments" which make me hold my breath and cross my fingers that he doesn't blow up along with his "rockets." It occurred to me there might be room for a bit of the lighter side of life in your austere magazine. If so, unbeknown to either my engineer husband or my son, I send you the composition, because I do think it is astonishing and may be more truth than poetry.

Robert is now so tall, that he is taken for 21. Though he is just 17 he is a contempo-

rary of his Dad's when they speak of electonics, nuclear physics, ionoscopes, plutrons, neutrons, and the rest—all of which is beyond my ken—my field being homemaking and gardens, into which I hope no rocket ever falls.

Forgive me, but we are entering this atomic age with our youth agitated and deeply concerned about the future. What our son has written may well be an indication of what other minds, less altruistic, also may be dreaming.

DOCTOR EIMER'S ROCKET

Finished! At last, after years of toil. Now Doctor Eimer would show those skeptical scientists. For the last ten years he had put all his efforts into the development of reaction motors. They had laughed at him when he claimed he would build a spaceship large enough and powerful enough to leave the earth. They spurned him when he asked for technical assistance.

It was way back in 1945 when Doctor Eimer began teaching physics and chemistry at the university that he had become interested in rockets. He read about the famous German V-2 rockets and decided to start experimentation. When Doctor Eimer's advanced students learned of his activities many decided to earn their research credits by assisting him. So Doctor Eimer really had not been too badly off. He had had all those eager young minds to help him.

In the following years, Doctor Eimer made many experiments, some successful, but even more unsuccessful. Doctor Eimer made many contributions to science through his experiments. He built and successfully operated metereological rockets that ascended to heights of several hundred miles and brought down information on the constitution of the atmosphere and the ionized layers of air which protect us from the sun. These rockets, however, were all alike in that they used energy from chemical reactions to propel them. Mainly the oxidation of alcohol by liquid oxygen. This was satisfactory for small rockets, but for large rockets the volume of fuel would necessitate a rocket of gigantic proportions —a factor which would make it inconceivable on this earth due to air resistance. Therefore Doctor Eimer turned to the only other source of energy, that energy which is released by nuclear reactions within the atom. But Doctor Eimer had still another problem. This energy was released as heat, not as volume of gas. Doctor Eimer, therefore, had to transform this heat into something which could be harnessed. After more experiments Doctor Eimer turned to lead, a fairly common metal having a low melting point and a great density. That was the answer. He would design a uranium motor that would vaporize lead.

So now, after ten years of effort, he had completed an atom-powered rocket capable of leaving the earth. It was over 75 feet long and ten feet wide at its greatest width. But Doctor Eimer had incorporated another unique item. It was two rockets in one. There was the big main rocket, and up in the top was a smaller rocket, the one which actually would reach the moon. Loaded in the head of the small rocket was a large quantity of powdered plaster which would leave a large white spot on the moon when it hit. The two-step rocket was mounted on a launching rack on the top of Mount Rainier. When all was ready on the fateful instant Doctor Eimer pushed the button which started the rocket's motors.

What would happen? Would it tear a gigantic hole in the earth, or would it reach the moon? No one knew.

* * *

But one thing is certain. Someday, someone will push such a button and the future of the world will be altered to a terrifying degree.

K. F. ZIMMERER
(Mineola, N. Y.)

English Engineer Seeks American Correspondent

To the Editor:

If it is at all possible I would like you to put me in touch with a young American engineer of approximately my own age (recent graduate), preferably residing in the New York area, with whom I could exchange correspondence. The reason for making this request is that I wish to obtain employment in the United States at some time in the future and would like to establish some contact and learn something of American methods before doing so.

ALFRED R. POLLARD
(9, Bullsmoor Gardens, Waltham Cross, Middlesex, England)

Evaluation of Circuit Constants From Oscillograms

To the Editor:

The shape of an oscillogram may depend in a large measure upon the values of the resistance, the inductance, and the capacitance present in the circuit. This investigation was made to determine whether the effects of these circuit factors upon the shape of the oscillogram were such as to permit the determination of these factors by an analysis of the oscillogram. Formulas are derived and applied to typical oscillograms of transients in series circuits, and it is shown that the results have an accuracy which makes the formulas and the method useful.

The oscillograph generally is used qualitatively, but its use quantitatively has been quite limited. Obviously, the accuracy of determinations made from an oscillogram is dependent upon the damping of the oscillograph element, the uniformity of the film speed, the warping of the film and of its print, the accuracy of the comparative scales on the record, and upon the care used in making measurements on the record. For the quantitative evaluation of R, L, and C the times, the instantaneous values, slopes, and areas must be measured from the oscillogram. The determination of a slope is subject to a relatively large error as at a point it is a matter of estimation by the eye.

To determine whether oscillograms under certain circumstances, could be analyzed to evaluate the circuit constants, or factors, and whether, if such analysis is feasible, the accuracy would be satisfactory, the writer, with the help of students, undertook the study here presented.

Case I. Given an oscillogram similar to Figure 1, with the impressed voltage E a known constant; to determine the R and the L of the circuit.

Since the general equation

$$i=\frac{E}{R}\left(1-\epsilon^{\frac{-Rt}{L}}\right)$$

must hold for all values of t, the time, the three arbitrary sets of conditions for t_1, t_2, and t_3 can be applied, so

$$i_1=\frac{E}{R}\left(1-\epsilon^{\frac{-Rt_1}{L}}\right) \tag{1}$$

$$i_2=\frac{E}{R}\left(1-\epsilon^{\frac{-Rt_2}{L}}\right) \tag{2}$$

$$i_3=\frac{E}{R}\left(1-\epsilon^{\frac{-Rt_3}{L}}\right) \tag{3}$$

If these are rewritten to

$$\epsilon^{\frac{-Rt_1}{L}}=1-\frac{i_1R}{E},\ \epsilon^{\frac{-Rt_2}{L}}=1-\frac{i_2R}{E}$$

and

$$\epsilon^{\frac{-Rt_2}{L}}=1-\frac{i_2R}{E}$$

and for equations 1 and 2 natural logarithms are taken,

$$\frac{-Rt_1}{L}=\log\left(1-\frac{i_1R}{E}\right)$$

and

$$\frac{-Rt_2}{L}=\log\left(1-\frac{i_2R}{E}\right)$$

and R/L is subtracted and factored out

$$\frac{R}{L}\left(t_2-t_1\right)=\log\left(\frac{E-i_2R}{E-i_1R}\right) \tag{4}$$

by symmetry

$$\frac{R}{L}\left(t_3-t_2\right)=\log\left(\frac{E-i_3R}{E-i_2R}\right) \tag{5}$$

Now, if the time intervals t_3-t_1 and t_3-t_2 are equal, equation 4 divided by equation 5 yields

$$1=\frac{\log\dfrac{E-i_1R}{E-i_2R}}{\log\dfrac{E-i_2R}{E-i_3R}}$$

and with the numerator and the denominator equal there results

$$R=\frac{E[2i_2-(i_1+i_3)]}{i_2^2-i_1i_3} \tag{6}$$

Equation 2 can be written

$$L=\frac{-Rt_2}{\log\left(1-\frac{Ri_2}{E}\right)} \tag{7}$$

which completes the solution for the two circuit factors R and L under the conditions given.

If the oscillogram represents a current subsidence and has the form of Figure 2, the current is

$$i=\frac{E}{R}e^{\frac{-Rt}{L}}$$

and at $t=0$, $R=\frac{E}{i}$, and to find L

$$\frac{Ri}{E}=e^{\frac{-Rt}{L}}$$

or

$$\frac{-Rt}{L}=\log\frac{Ri}{E}$$

Substituting for the two values of time t_1 and t_2 the corresponding currents, i_1 and i_2, yields

$$L=\frac{R(t_2-t_1)}{\log\frac{i_1}{i_2}}$$

If di/dt can be evaluated at $t=0$

$$\frac{di}{dt}=-\frac{E}{L}e^{\frac{-Rt}{L}}$$

it becomes $-E/L$ and

$$L=-\frac{E}{di/dt}$$

using di/dt at $t=0$.

Case II. Given an oscillogram similar to Figure 3, with a known constant voltage of E, to determine R and C. Except for signs, the charging and the discharging currents may be represented by

$$i=\frac{E}{R}e^{\frac{-t}{CR}}$$

and at $t=0$, $R=E/i$. If the currents i_1 and i_3 are substituted into the general formula for the two values of time t_1 and t_3 and natural logarithms are taken,

$$C=\frac{t_2-t_1}{R\log\frac{i_1}{i_2}}$$

Case III. In considering oscillograms of circuits having R, L, and C in series, separate treatments are given to the oscillatory, critical, and logarithmic cases.

For the oscillatory case, with an oscillogram of the form of Figure 4: The natural frequency is

$$f=\frac{\sqrt{4LC-C^2R^2}}{4\pi LC}$$

so that the time T, between adjacent zero values of current is

$$T=\frac{2\pi LC}{\sqrt{4LC-C^2R^2}} \tag{8}$$

a value to be scaled from the oscillogram by means of the timing curve.

The ratio between the amplitudes at t_2 and t_1 is the decrement factor which is

$$\delta=e^{-\frac{R}{2L}(t_2t_1)}$$

whence, by natural logarithms

$$\frac{R}{2L}=\frac{-\log\delta}{t_2-t_1} \tag{9}$$

The current at any time t is

$$i=\frac{e^{\frac{-Rt}{2L}}2EC}{\sqrt{4LC-C^2R^2}}\sin\left(\frac{\sqrt{4LC-C^2R^2}}{2CL}\right)t \tag{10}$$

From equation 8

$$\frac{2CL}{\sqrt{4LC-C^2R^2}}=\frac{T}{\pi}$$

Figure 1

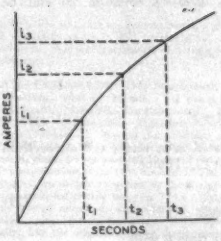


Figure 2

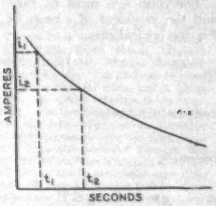


Figure 3 (left)

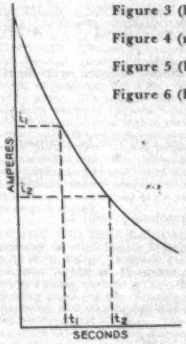


Figure 4 (right)

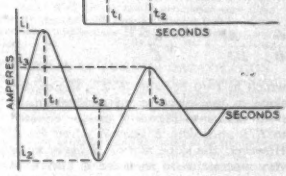


Figure 5 (below)

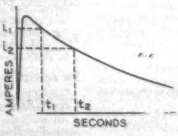
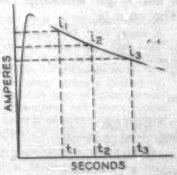


Figure 6 (below right)



a known value as T can be scaled from the oscillogram.

Also

$$\frac{2CE}{\sqrt{4LC-C^2R^2}}=\frac{ET}{\pi L}$$

and from equation 9

$$-\frac{Rt}{2L}=\frac{t\log\delta}{t_2-t_1}=\frac{t\log\delta}{T}$$

Substituting into equation 10

$$=e^{\frac{t\log\delta}{T}}\frac{ET}{\pi L}\sin\frac{\pi t}{T}$$

and then

$$L=e^{\frac{t\log\delta}{T}}\frac{ET}{\pi i}\sin\frac{\pi t}{T} \tag{11}$$

where i and t are corresponding values.

It is convenient to have $\sin \pi t/T$ equal unity. If L is known, then

$$R=\frac{-2L\log\delta}{T} \tag{12}$$

and

$$C=\frac{T^2}{\pi^2L+\left(\frac{RT}{2\sqrt{L}}\right)^2} \tag{13}$$

If in equation 11 t is taken as $T/2$ and used as t_1 with i_1,

$$L=\frac{ET}{\pi i_1}e^{\frac{t}{T}\log\frac{t_2}{t_1}} \tag{14}$$

The ratio i_2/i_1 must be taken positive, and the exponent of e must be negative. For the critical case,

$$R^2=\frac{4L}{C}$$

and the current is

$$i=\frac{E}{L}te^{\frac{-Rt}{2L}} \tag{15}$$

$$\frac{di}{dt}=\frac{-REt}{2L^2}e^{\frac{-Rt}{2L}}+\frac{E}{L}e^{\frac{-Rt}{2L}}$$

which at $t=0$ becomes E/L. Hence, the slope of the curve of an oscillogram, at $t=0$, similar to Figure 5, can be equated to E/L and, with E known, solved for L. However, the slope at $t=0$ is likely to be very uncertain, so measure i_1 and i_2 at t_1 and t_2 and substitute into equation 15. The ratio is

$$\frac{i_1}{i_2}=\frac{t_1}{t_2}e^{\frac{R}{2L}(t_1-t_2)} \tag{16}$$

so

$$\log_e\frac{i_1t_2}{i_2t_1}=\frac{R}{2L}(t_2-t_1)$$

and

$$\frac{Rt}{2L}=\frac{t}{t_2-t_1}\log_e\frac{i_1t_2}{i_2t_1} \tag{17}$$

This into equation 15 yields

$$L=\frac{Et}{i}e^{\frac{-t}{t_2-t_1}\log\frac{i_1t_2}{i_2t_1}} \tag{18}$$

where t and i are corresponding values. If these are identical with t_1 and i_1, then

$$L=\frac{Et_1}{i_1}e^{\frac{-t_1}{t_2-t_1}\log\frac{i_1t_2}{i_2t_1}} \tag{19}$$

and

$$\frac{i_1t_2}{i_2t_1}$$ is a positive fraction.

So from equation 16

$$R=\frac{-2L}{t}\log_e\frac{iL}{Et}$$

where i and t are corresponding values. Finally $C=4L/R^2$.

The oscillogram for a logarithmic case has the form of Figure 6. With a constant impressed voltage

$$Ri+L\frac{di}{dt}+\frac{q}{C}=E \tag{20}$$

where

$$q=\int_0^t idt$$

and is the charge in the capacitor at the instant t, starting with zero charge at $t=0$. If the oscillogram is of such form that the time t' can be found for maximum current at which $di/dt=0$, equation 20 can be written

$$Ri_{max}+\frac{q'}{C}=E$$

where

$$q'=\int_0^{t'}idt=S'$$

the evaluated area under the curve from $t=0$ to $t=t'$. Hence

$$C=\frac{S'}{E-Ri_{max}} \tag{21}$$

At another time t_2 with

$$S_2=\int_0^{t_2}idt \qquad \frac{S_2}{C}=E-Ri_2-L\frac{di_2}{dt} \tag{22}$$

If equation 20 is evaluated at $t=0$, it is

$$di/dt=E/L \tag{23}$$

So if the slope at $t=0$ can be evaluated,

$$L=\frac{E}{di/dt} \tag{24}$$

By rewriting equations 21 and 22

$$CE-CRi_1=S_1$$

and dividing equation 21 by 22

$$CE-CRi_2-CL\frac{di_2}{dt}=S_2$$

$$R=\frac{E(S_1-S_2)-LS_1\frac{di_2}{dt}}{i_2S_1-i_1S_2} \tag{25}$$

which with equation 21 gives C.

However, evaluation at $t=0$ may not be satisfactory.

In equation 20 let t have the values t_1, t_2, and t_3 with the corresponding slopes di_1/dt, di_2/dt, and di_3/dt and corresponding areas under the curve of S_1, S_2, and S_3. If these are substituted into equation 20 and the resulting equations solved, there results

$$L=\frac{E[(i_3-i_1)(S_2i_3-S_3i_2)-(i_3-i_2)(S_1i_3-S_3i_1)]}{i_3\left[\frac{di_1}{dt}(S_2i_3-S_3i_2)+\frac{di_2}{dt}(S_3i_1-S_1i_3)+\frac{di_3}{dt}(S_1i_2-S_2i_1)\right]} \tag{26}$$

where the currents are of positive sign but the rates are negative. Let this value of L be L_e, substitute this into equation 20 for the values of time t_2 and t_3, and solve,

$$R=\frac{E(S_2-S_3)+L_e\left(S_3\frac{di_2}{dt}-S_2\frac{di_3}{dt}\right)}{S_2i_3-S_3i_2} \tag{27}$$

and if this value of R be R_e, then

$$C=\frac{S_2}{E-i_2R_e-L_e\frac{di_2}{dt}} \tag{28}$$

To test these formulas oscillograms were supplied by Professor B. K. Osborn of Michigan State College. These were taken on a style S011D370 Westinghouse oscillograph. Blueprints were made and given to a class of 25 students to measure and to evaluate the factors R, L, and C. The results show that, notwithstanding distortion of the film and of the prints and the errors inherent in the measurement of slopes and areas, the accuracy was good when the average of several determinations was taken. Resistances were found to one half of one per cent, inductances to three per cent, and capacitances to one and one half per cent accuracy when compared with the results of the usual laboratory methods of measurement. Artificial oscillograms plotted from computed data and analyzed by these methods produced exact checks on the assumed circuit factors.

Under proper conditions evaluation of an oscillogram may show changes in the circuit factors. The effective resistance of a circuit may change with di/dt which is related to frequency. The method permits testing of the oscillograph itself. An oscillogram taken on a circuit of known constants should analyze into those same constants, and, if it does not, adjustments should be made. Records were found to be very sensitive to the degree of damping.

L. S. FOLTZ (M '25)

(Professor and head of electrical engineering department, Michigan State College, East Lansing, Mich.)

AIEE Member Runs for Congress

To the Editor:

It was not my intention to become a politician. The honor was thrust upon me. I'm a candidate for Member of Congress, 10th Congressional District, Kings County, N. Y., and I'm writing to all of my friends for their support. As a Member for Life of the AIEE, I feel that the membership of the Institute would be interested in my behalf.

My district comprises Stuyvesant Heights, Bedford District, and Flatbush bounded at one end by Ralph Avenue and on the other by Flatlands Avenue.

VIC WICHUM (A '07, M '37)

(Recently a major in the Ordnance Department, Army of the United States, and formerly chief engineer, C. J. Tagliabue Company, Brooklyn, N. Y.)

NEW BOOKS....

"Aircraft Electricity for the Mechanic." Though this manual was prepared primarily for men handling aircraft who are not electrical engineers, the author also had in mind electrical engineers who are not concerned specifically with aircraft. Before it was printed, the manuscript was

used by the author in teaching aircraft electric and ignition systems to officers and enlisted men of the Army, Navy, and Marine Corps, as well as civilian students who were being trained to become pilots, maintenance supervisors, and mechanics. It is written so that it can be used in preparing for promotion examinations in the armed services and for examinations given by the Civil Aeronautics Administration to applicants for licenses as aircraft mechanics and aircraft engine mechanics. The fundamentals of electricity and of the aircraft electric system and its operation, maintenance, and inspection are explained. The most common troubles encountered in actual operation, their possible causes, the symptoms by which they are recognized, and the solutions for these problems are presented. Typical examination questions, a section on getting a job, and a comprehensive index are included. By Charles Edward Chapel. Coward McCann, Inc., New York, N. Y., 1946, 5¼ by 8¼ inches, cloth, 477 pages, $5.

"A Chronological History of Electrical Development." Commencing with the discovery of static electricity by the Greek, Thales, in 600 B.C., and continuing through several listings for 1944, this history records in brief paragraphs the pertinent facts about the first known accounts of theories, research, experiments, discoveries, and inventions contributing to present electrical knowledge. Dates of other historic occasions—electrical expositions, and congresses; the birth of electrical publications, engineering and trade association, societies, foundations, and institutes—also are given. The book is intended as a reference work for editors, writers, commentators, libraries, and schools, as well as for industry. An appendix giving the present and original names, the founder, and date of founding of the chief electrical companies in the United States is included. National Electrical Manufacturers Association, New York 17, N. Y., 1946, 6 by 9¼ inches, 106 pages plus appendix, cloth, $2.

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

PHOTOGRAPHY IN ENGINEERING. By C. H. S. Tupholme. Faber and Faber Ltd. and the Hyperion Press Ltd., London, England, 1945. 276 pages, illustrated, 9½ by 7 inches, cloth, 42s. The ways in which the camera is being used to simplify the draftsman's work, to analyze raw materials, to make records of high-speed machinery, in studying the molecular structure of metals, and in other ways are presented in this volume, which summarizes conveniently much scattered literature. Bibliographies provide for further study.

MANIFESTO FOR THE ATOMIC AGE. By V. Jordan. Rutgers University Press, New Brunswick, N. J., 1946. 70 pages, 7½ by 5 inches, cloth, $1.50. The impact of the release of atomic energy upon the industrial and social framework of human life is assessed in the light of the current uncertain state of affairs. The results of previous revolutionary changes in the world situation are demonstrated, and a forecast of the likely shifts in the technological, economic, biological, and political aspects of human existence is presented.

ASTM STANDARDS. 1945 Supplement, including Tentatives. Part I. Metals. 397 pages. Part II. Nonmetallic Materials—Constructional. 229 pages. Part III. Nonmetallic Materials—General. 503 pages. American Society for Testing Materials, Philadelphia 2, Pa., 1945–1946, illustrated, 9½ by 6 inches, cloth, $4 per part ($2.50 to ASTM members). This supplement to the 1944 book of ASTM Standards brings it up to date by giving all the changes or additions accepted during the year 1945. Two hundred and fifteen standards are included, some sixty of which appear for the first time. The supplement appears, like the original work in three volumes.

AMERICAN SOCIETY FOR TESTING MATERIALS, 1944 SUPPLEMENT TO THE BIBLIOGRAPHY AND ABSTRACTS ON ELECTRICAL CONTACTS. Prepared by Committee B-4 on Electrical-Heating, Electrical-Resistance and Electric-Furnace Alloys, American Society for Testing Materials, Philadelphia, Pa., 1945. 30 pages, 9 by 6 inches, paper. The original "Bibliography and Abstracts on Electrical Contacts," published in 1944, covered the period from 1835 to 1942. This first supplement contains some eighty items within that period which had not been included previously and carries on through 1943 into 1944. As before, an author and subject index are provided. A wide range of material is considered, and the abstracts are extensive enough for adequate determination of the particular value of the original articles.

ATOMIC AND FREE RADICAL REACTIONS. American Chemical Society Monograph Series 102. By E. W. R. Steacie. Reinhold Publishing Corporation, New York, N. Y., 1946. 548 pages, illustrated, 9¼ by 6 inches, cloth, $8. The elementary reactions involving atoms and free radicals are of considerable importance in explaining the mechanism of thermal and photochemical reactions. This book brings together the existing data and discusses the kinetics of these elementary reactions. The material is restricted to reactions involving organic substances, mainly in the gaseous state. A reaction index and table of activation energies are included. Extensive reference to further material is made in footnotes.

ATOMIC ARTILLERY AND THE ATOMIC BOMB. By J. K. Robertson. D. Van Nostrand Company, New York, N. Y., 1945. 173 pages, illustrated, 7½ by 5 inches, cloth, $2.50. In simple language, without mathematics, this book treats of the equivalence and interconversion of mass and energy, the meaning of nuclear fission and nuclear chain reactions, and the major details of construction of the plants for producing atomic power and atomic explosives. The early work on the passage of electricity through gases leads into the discussion of electrons and the heavier, faster types of particles so important in our newer fields of science, such as the release and control of atomic energy.

CAVENDISH LABORATORY. By A. Wood. University Press, Cambridge, England; The Macmillan Company, New York, N. Y., 1946. 59 pages, illustrated, 6¾ by 4 inches, cardboard, $1. In the 72 years since the Cavendish Laboratory was opened, it has become famous as a leader in physical developments. This book briefly describes the development of the laboratory under Clerk-Maxwell, Rayleigh, J. J. Thomson, and Rutherford and calls attention to some epoch-making results.

COURS D'ANALYSE INFINITÉSIMALE. Two volumes. By Ch.-J. de la Vallée Poussin. Volume 1, eighth edition, 460 pages; volume 2, seventh edition revised, 524 pages, 1946. Dover Publications, New York, N. Y., illustrated, 8¾ by 5½ inches, cloth, $4 each (2 volumes, $7.50). This standard French text provides both a working knowledge of advanced calculus for the technical student and the basis for a thorough understanding of the fundamental principles of analysis for the student of mathematics. Volume I deals with the differentiation of implicit and explicit functions of one or more variables, with the classic methods of integration, and with the fundamental formulas of the theories of curves and surfaces. Volume II continues the work on various types of integrals, takes up differential equations and the calculi of variations and of finite differences, and goes thoroughly into the subject of geometrical applications.

THIN FILMS AND SURFACES. By W. Lewis Published for Temple Press, Ltd., by English Universities Press, Ltd., Little Paul's House, Warwick Square, London, England, 1946. 70 pages, illustrated, 8¾ by 5½ inches, cloth, 15s. The structure of metal surfaces and of surface films (of oxide, and so forth) is considered first, with special reference to the structure of thin films. The production of thin metallic films next is dealt with, followed by a section discussing the mechanical, optical, magnetic, and electrical properties of metallic films and surfaces. The last two chapters collect what information is relevant about the properties of aluminum, briefly summarize some comparative data for other metals, and refer to some of the interesting applications of aluminum films and surfaces.

PRINCIPLES OF BUSINESS ORGANIZATION. By W. R. Spriegel and E. C. Davies. Prentice-Hall, Inc., New York, N. Y., 1946. 564 pages, illustrated, 9¼ by 6 inches, cloth, $6.35. The material presented in this book is divided into the following major sections: ownership and structural forms of a business enterprise; promotion and operation of an enterprise; financial considerations; accounts and records; the manufacturing function; the marketing function; personnel maintenance.

PRACTICAL OPTICS. By B. K. Johnson. Hatton Press, Ltd., London, England, 1943. 189 pages, illustrated, 9 by 5½ inches, cloth, 15s. This small volume presents the practical application of optical principles. These principles are discussed in the first two chapters, with succeeding chapters dealing respectively with the three main types of optical instruments: telescopes, microscopes, and photographic lenses. A separate chapter is devoted to the working and testing of optical glass.

PERSONALITY AND ENGLISH IN TECHNICAL PERSONNEL. By P. B. McDonald. D. Van Nostrand Company, New York, N. Y., 1946. 424 pages, 8¾ by 5½ inches, cloth, $3.75. This book emphasizes the importance of developing a definite personality, an accurate command of English, and effective methods for presenting ideas, both written and verbal, with specific suggestions for improvement in these particulars.

OFFICE LIBRARY OF AN INDUSTRIAL RELATIONS EXECUTIVE. Prepared by H. Baker. Fifth edition. Princeton University, Princeton, N. J., 1946. 36 pages, 9 by 6 inches, paper, 50 cents. A considerable list of recommended books, pamphlets, and periodicals for the industrial relations executive is presented under the following general headings: general works; specific personnel problems and programs; trade unions and collective bargaining; labor legislation and administration; social insurance.

INDUSTRIAL ECONOMY AND LABOR CONTROL. By W. L. McNaughton. Golden State Publishers, Village Station, Los Angeles 24, Calif., 1945. 273 pages, illustrated, 8 by 5¼ inches, cloth, $3.25; paper, $2.75. Dealing chiefly with motion and time study, this book devotes the first two sections to discussion of the importance and purpose of their application in an industrial plant. The succeeding three sections take up the practical aspects of plant layout, time study and motion economy, including materials handling and tool positioning.

INDUCTION HEATING. By H. B. Osborn and others. American Society for Metals, Cleveland, Ohio, 1946. 172 pages, illustrated, 9¼ by 6 inches, cloth, $3. Five lectures presented at the 1946 National Metal Congress are combined in this book. They deal respectively with: the principles and theory of high frequency heating; induction heating circuits and frequency generation; practical applications of the motor-generator type of induction heating (up to 10,000 cycles); practical applications of high frequency induction heating (100,000 cycles and up); and a comparison of induction heating with other methods of heat treating.

HIGH VACUUM TECHNIQUE. By J. Yarwood. Second edition revised, John Wiley and Sons, New York, N. Y.; Chapman and Hall, London, England, 1945. 140 pages, illustrated, 9¼ by 6 inches, cloth, $2.75. This book describes the basic theories, standard techniques, methods of measurement, and industrial applications of high vacuums, with explanations of the physical bases of the methods adopted. The latest developments in apparatus are introduced, important industrial processes are outlined, and considerable factual material is presented regarding the relevant properties and uses of materials encountered in all types of vacuum work.

GERMAN FOR THE SCIENTIST. By P. F. Wiener, with an introduction by E. N. da C. Andrade. First American edition with additional sections and foreword by P. Spoerri. Chemical Publishing Company, Brooklyn, N. Y., 1946. 238 pages, illustrated, 7½ by 5 inches, cloth, $3.50. Following a brief introductory section on German grammar, the author presents passages taken from the literature of chemistry and physics. These passages have been chosen from books obtainable in English to allow the student to carry on with any subject matter of interest to him, and have been selected for their content of basic German scientific words. The final section contains the English translations of the German passages. There is a vocabulary.

ELEMENTARY WAVE MECHANICS. By W. Heitler. The Clarendon Press, Oxford, England; Oxford University Press, New York, N. Y., 1945. 136 pages, illustrated, 7½ by 5 inches, cloth, $2.25. Beginning with chapters on the experimental basis of quantum mechanics and the derivation of the wave equation, the author proceeds to discuss the hydrogen atom, angular momentum and spin, the problem of two electrons, perturbation theory, and the periodic system of elements. The last two chapters provide an introduction to the theory of chemical bond.

MÉTROLOGIE GÉNÉRALE. By M. Denis-Papin and J. Vallot. Dunod, Paris, France, 1946. 428 pages, illustrated, 6 by 4 inches, fabrikoid, 240 francs. This comprehensive manual covers the field of measurement from a broad point of view. Early chapters are devoted to a discussion of measurement in general, the international system of weights and measures, and the symbols and equations of fundamental systems of measurement. Methods of measurement and units described for the fields of geometry, geography, mechanics, angular measure, stresses, electricity, and magnetism, heat and radiant energy, optics and time. Special industries, ancient and foreign units are covered.

INSTRUMENTS AND PROCESS CONTROL. New York State Vocational and Practical Arts Association, Albany, N. Y.; distributed by Delmar Publishers, Inc., Albany 6, N. Y., 1945. 233 pages, illustrated, 11 by 8½ inches, paper, ring binder, $2.75. The general principles of process control are discussed, and a large number of instruments for specific control operations are described and illustrated. Mechanical, electrical, hydraulic and pneumatic control methods are included, and the name of the manufacturer is given for each instrument shown.

INDUSTRIAL RESEARCH 1946. Advisory Editor, E. N. da C. Andrade. Todd Publishing Company, London, England, and New York, N. Y. Sole British Distributors: George G. Harrap and Company, Ltd., 1946. 736 pages, 9 by 5½ inches, cloth, $6. This British reference book presents first some 30 brief articles by specialists on various aspects—technical, educational, financial—of the important fields of industrial research. Succeeding sections contain classified directories of official trade and technical research organizations in Great Britain, and also lists of university and industrial research laboratories. A section discussing careers in industrial research includes courses available in universities and membership requirements for technical societies.

INDUSTRIAL RELATIONS AND THE SOCIAL ORDER. By W. E. Moore. Macmillan Company, New York, N. Y., 1946. 555 pages, illustrated, 8½ by 5½ inches, cloth, $4. Intended to supplement the standard treatments of industrial organization and relations, this book emphasizes the viewpoint of modern industry as a complex social organization. Following a discussion of the development of modern industry, connected sections dealing with management and managerial functions, the sources and effective use of labor, and industrial relations. The final part discusses the interrelation of industry and society in general, including economic planning.

AMINOPLASTES. By P. Talet. Préface by J. Duclaux. Dunod, Paris, France, 1946. 235 pages, illustrated, 9 by 5½ inches, paper, 280 francs. Following a statement of the general theory comes a brief description of the raw materials, urea and formaldehyde. The methods of formation are dealt with, covering the condensation, dehydration, and hardening processes. The preparation of molding powders and the methods of molding are treated in some detail. Several brief chapters take up such uses, as coatings and impregnation. Finally, some 50 pages are devoted to various modifications: the replacement of urea by other nitrogen compounds, for example, and similar treatments.

ATOMIC ENERGY IN COSMIC AND HUMAN LIFE. By G. Gamow. University Press, Cambridge, England; Macmillan Company, New York, N. Y., 1946. 161 pages, illustrated, 8½ by 5½ inches, cloth, $3. In the first section the author takes up the question of what atomic energy is and describes how atomic transformations are brought about. In the second section he describes the way in which these transformations are used by and produced in the stars. The final section discusses the problem of how man can use atomic energy, utilizing the method of neutron multiplication and bombardment as described.

BASIC MATHEMATICS FOR RADIO STUDENTS. By F. M. Colebrook. Wireless World. Iliffe and Sons, Ltd., London, England, 1946. 270 pages, illustrated, 7 by 4½ inches, cloth, 10*s.* 6*d.* The author's intent is to give the student a thorough groundwork in the basic ideas of elementary mathematics rather than a condensed statement of rules and formulas. The topics covered include algebra-indexes and logarithms, equations and complex numbers, limits and series, geometry, trigonometry, and differential and integral calculus. These chapters are all quite general, and suitable for any scientific or technical student. The special treatment appears only in the last chapter on the application of mathematical ideas to radio.

CORROSION OF METALS. By C. W. Borgmann, C. P. Larrabee, W. O. Binder, H. L. Burghoff, and E. H. Dix, Jr. American Society for Metals, Cleveland, Ohio, 1946. 181 pages, illustrated, 9¼ by 6 inches, fabrikoid, $3. In this small volume are reprinted five lectures presented at the 1946 National Metal Congress. The titles are: basic principles of metallic corrosion, effect of composition and environment on corrosion of iron and steel, corrosion resistance of stainless steels and high nickel alloys, copper and copper alloys in corrosive environments and corrosion of light metals.

DIESEL-ELECTRIC LOCOMOTIVE. By C. F. Foell and M. E. Thompson. Diesel Publications, New York, N. Y., 1946. 688 pages, illustrated, 9½ by 6 inches, cloth, $7, United States; $8, elsewhere. The early chapters of this book cover the history, development, advantages, and classification of Diesel-electric locomotives. The remainder of the book deals with the constructional, engineering, operational, and maintenance aspects of the subject. Two chapters of general engineering fundamentals are included, and Diesel-hydraulic and Diesel-mechanical locomotives are given brief consideration.

ELECTRICAL ENGINEERING PROBLEMS. By W. Glendinning, 5123 Bell Boulevard, Bayside, N. Y., 1946. 112 pages, illustrated, 8½ by 11½ inches, paper, $3. This manual provides questions and solutions to the electrical engineering problems of 15 past examinations in professional engineering—Part III, Electrical Engineering, Group D—given to applicants for the license of professional engineer in New York State. Useful in preparing for professional engineering and civil service examinations, the material covers various types of problems in d-c and a-c machinery and in power and communication systems.

ELECTRON AND NUCLEAR COUNTERS. By S. A. Korff. D. Van Nostrand Company, New York, N. Y., 1946. 212 pages, illustrated, 8½ by 5½ inches, cloth, $3. This book first discusses the internal mechanism of the discharge in electron and nuclear counters, then presents the constructional and operational features which are desirable and the best means for securing them, with discussion of the errors and corrections encountered in using the devices. Finally, the various electronic circuits which are the essential auxiliaries to successful operation are considered in some detail. Selectively sensitive and other special counters are covered as well as the conventional Geiger type.

ELECTRONS, ATOMS, MOLECULES. By A. C. Crehore. Christopher Publishing House, Boston, Mass., 1946. 133 pages, illustrated, 8½ by 5½ inches, fabrikoid, $3.75. The author presents his basis for hypothesizing a stable atom, and demonstrates his point by the mathematical analysis of the phenomena of molecule formation, crystal structure, and so forth. Energy determinations resulting from thermochemical investigations are used to a considerable extent in developing the conceptions put forth.

PAMPHLETS . . .

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers

The Physically Handicapped Worker in Industry. By Gilbert Brighouse. California Institute of Technology, Pasadena 4, Calif., 54 pages, $2.

Maintenance of Industrial Electronic Equipment. Westinghouse Electric Corporation, P. O. Box 868, Pittsburgh 30, Pa., 30 pages, no charge.

New Products and Services. *New York Journal of Commerce*, 63 Park Row, New York 15, N. Y., 32 pages, 50 cents.

New Code Changes Show Progress in Branch Circuit Wiring (chart). United States Rubber Company, 1230 Avenue of the Americas, New York 20, N. Y., no charge.

1945–46 Year Book. American Standards Association, 70 East 45th Street, New York 17, N. Y., no charge.

International Trade Handbook. Committee for Economic Development, 285 Madison Avenue, New York 17, N. Y., 50 cents.

The ABC's of Modern Plastics. Bakelite Corporation, 300 Madison Avenue, New York 17, N. Y., 35 pages, no charge.

Recommended Practices for Automotive Flash-Butt Welding. American Welding Society, 33 West 39th Street, New York 18, N. Y., 22 pages, 30 cents.

RFC Small Business Activities. Reconstruction Finance Corporation, Washington 25, D. C., 15 pages.

Report of Tests on Fires in Magnesium Castings. Factory Mutual Laboratories, 184 High Street, Boston 10, Mass., 11 pages, no charge.

Memorandum on Servomechanisms. G. C. Wilson and Company, P. O. Box 389, Chatham, N. J., no charge.

Your Place in the Sun. General Electric Company, Nela Park, Cleveland 12, Ohio, 23 pages, 10 cents.

Applications and Economics of the Diesel Engine. By Harvey T. Hill. Diesel Engine Manufacturers Association, 1 North La Salle Street, Chicago 2, Ill., 15 pages.

Airline Airport Design Recommendations. Part I. Airport Requirements, Airport Location, Classification of Airports, Aprons, Runway Clearances, Runway Configurations, 43 pages. Part IV. Airport Lighting, 33 pages. Air Transport Association of America, 1107 16th Street N. W., Washington 6, D. C.

Rod Selector Chart. Eutectic Welding Alloys Corporation, 40 Worth Street, New York 13, N. Y., no charge.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Design of D-C Auxiliary Controllers for Marine Service

W. SCHAELCHLIN
MEMBER AIEE

CONSIDERABLE progress has been made in recent years in the design of marine control equipment. Under the impact of the war, the performance of controllers has been improved and better equipment of lighter weight has been made available. It is the purpose of this paper to discuss some of the more important design features on which the controller performance is based.

Controller Components

The function of a motor starter is to connect the motor across the line without excessive disturbance to the motor or the power supply. The simpler the equipment used for this purpose, the more satisfactory, in general, it will be in service.

There are a great variety of motor starters, ranging from the simple manual line starter to the more complex magnetic controller. Different methods of automatic acceleration are used with the number of starting steps varying to suit the application and rating of the motor. Other design features, such as overload protection and selection of resistors have an equally important bearing on the controller performance.

Paper 46-127, recommended by the AIEE committee on marine transportation for presentation at the AIEE summer convention, Detroit, Mich., June 24–28, 1946. Manuscript submitted October 18, 1945; made available for printing May 10, 1946.

W. SCHAELCHLIN is with the Westinghouse Electric Corporation, East Pittsburgh, Pa.

Number of Starting Steps

The current surges during starting of a motor depend primarily upon the number of starting steps and the regulation of the motor. This relation can be solved mathematically but perhaps is more clearly illustrated in Figure 1 from a typical shunt motor with 10-per-cent speed regulation and a constant torque load of 100 per cent.

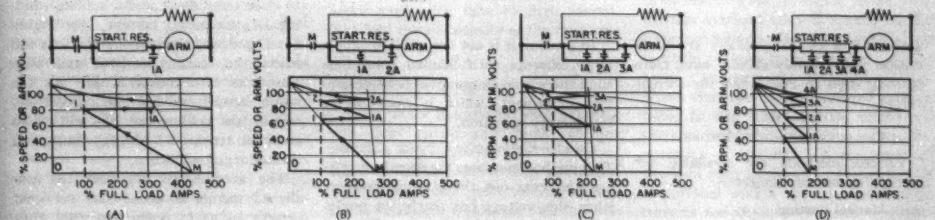


Figure 1. Schematic diagram and current surges for various numbers of starting steps

On closing the line contactor M, the armature current increases from 0 to M. As the motor accelerates, this current decreases to one, at which point the accelerating contactor $1A$ cuts out the starting resistor and connects the motor across the line. For multistep starters, this process is repeated by operating accelerators $1A$, $2A$, $3A$, $4A$, and so forth, in sequence until the starting sequence is completed.

Figure 1 illustrates clearly that the starting current surges can be reduced by increasing the number of steps. This fact is taken into consideration by providing more steps for large motors than for small motors. Table I shows standard number of starting steps and approximate maximum current surges for various motor ratings.

Further reference to Figure 1 indicates that the starting current surge is made higher for the low armature speeds than for the high armature speeds. This is done because the average motor can commutate current surges better at low speed than at high speed, a fact which is well illustrated in Figure 2.

This oscillogram shows a starting test with a standard 3-horsepower 250-volt motor connected directly across the line without a resistor step. Commutation was fairly good at low speed even though the current inrush was about 1,300 per cent. At approximately full speed, however, the motor flashed over, although the current had decreased to about 750 per cent.

Of additional interest is the fluctuation of the field current I_f during the starting of the motor. This current suddenly increased several hundred per cent, which indicates a pronounced weakening of the flux due to the armature reaction. The subsequent dip of I_f below the normal value is due to the line voltage disturbance caused by the short circuit.

Applications with high inertia loads

Table I. Number of Starting Steps and Maximum Current Surges for Various Motor Ratings

Hp at 230 V	Number of Starting Steps	Approximate Current Surge, Per Cent Full Load Amp
1/3	0	1,000
3 to 5	1	450
7½ to 25	2	275
30 to 40	3	225
50 to 150	4	175

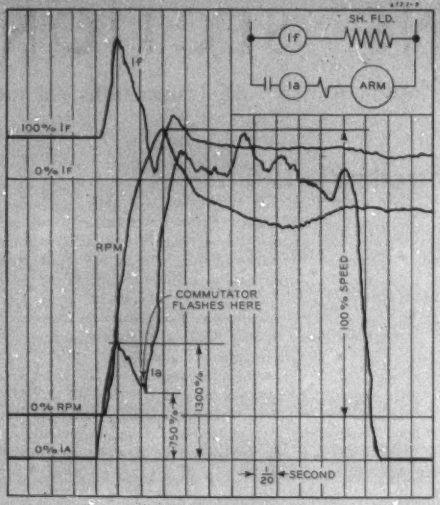


Figure 2 (left). Oscillogram showing line starting of 3-horsepower 250-volt shunt motor

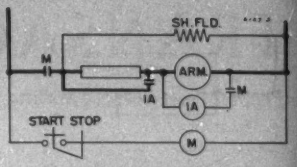


Figure 3. Starter diagram with counter-electromotive force acceleration

such as fans and oil purifiers are more critical and possibly should have more starting steps to keep down the current surges.

Methods of Starting of Motors

Various methods are available for starting of motors, namely—

(*a*). Manual starting.
(*b*). Counter-electromotive force starting.
(*c*). Current limit acceleration.
(*d*). Definite time acceleration.

Manual Starter. This type of starter undoubtedly provides the simplest means of starting a motor. It is particularly suitable for motors up to one half of one horsepower where the stalled armature current does not exceed 1,000 per cent. Sometimes it is provided with a starting step for use with motors up to five horsepower. In such cases, the operating lever may be equipped with a mechanical offset to make the operator pause on the start position before going to the run position.

In general, it is not desirable to handle large currents with manual controllers since there is no assurance of positive contact movement, which is essential for satisfactory operation.

Counter-Electromotive Force Starting. This method measures the armature voltage and cuts out the starting resistors when this voltage has reached a predetermined value. A schematic diagram, which is self-explanatory, is shown in Figure 3.

The counter-electromotive force starter is somewhat critical in its adjustment and can be used only for single-step starters. Figure 1A shows that the accelerating contactor 1*A* has to be adjusted to operate at 70–80 per cent in order to avoid an excessive current surge when it closes. With possible line voltage drops of 20 per cent this setting is rather critical, particularly if the pull-in voltage is increased due to heating of the magnet coil.

Multistep starters of the counter-electromotive force type would require even a higher setting of the last accelerating contactor as shown in Figure 1B, which makes use of the counter-electromotive force method for multistep starters impractical.

Current Limit Acceleration. This method is suitable equally for starting low and high inertia loads and will bring the motor up to speed in a minimum of time. A one-step starter of this type is shown in Figure 4.

The accelerator 1*A* is of the spring closed type and has a main winding $1A_M$ to close the magnet and a holding winding $1A_H$ measuring current. See Figure 5. Depressing the start button first will insert the starting resistor and then close the line contactor *M*. As the motor accelerates and the current decreases, the holding coil $1A_H$ will let go and close contact 1*A*, thereby connecting the motor across the line.

The accelerators are calibrated usually to operate at about 135 per cent current so as to make sure that they function when starting heavy loads. Thus the current surges will be somewhat higher than indicated in Figure 1.

Definite Time Acceleration. Definite time starting probably is the most practical method of bringing a motor up to speed. It includes one or more accelerators adjusted to function in predetermined time intervals. A single-step starter is shown in Figure 6.

The accelerator or "timetactor" operates on the basis of the well-known and reliable flux decay principle and is shown in sizes of 100 and 300 amperes in Figure

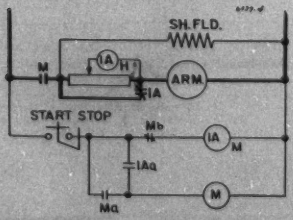


Figure 4 (left). Starter diagram with current limit acceleration

Figure 5 (right). Accelerating contactors for current limit or definite time acceleration

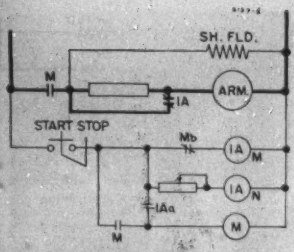


Figure 6. Starter diagram with definite time acceleration

5. In general, the time starter is identical to the controller of Figure 4 except that the accelerator is connected to obtain a fixed time instead of measuring current. Time adjustment is obtained by changing the current in the neutralizing winding $1A_M$.

There is, of course, the problem of selecting the proper time adjustment for the timetactors, so that the motor can accelerate without excessive current surges. This, however, should not be too difficult a task since starting conditions for the various ships' auxiliaries are well known and it is therefore a simple matter to adjust the accelerating time slightly longer than needed to obtain minimum current surges. Definite time starters can be tested and adjusted very readily with the motor disconnected and therefore have a decided advantage from a maintenance point of view.

Speed Control

The speed of a d-c motor may be controlled by varying the armature voltage or the strength of its field. Motors below five horsepower used for hull ventilation sometimes are provided with armature speed control in order to reduce the motor size. This gain, however, is practically offset by the increased size of the controller which has to absorb the resistor loss as shown in Figure 7.

In most cases, the motor speed is changed by varying the shunt field. Motors with speed changes of two to one or less have sufficient starting torque to permit good starting with weak field. The torque tests shown in Figure 8 were made with a 20-horsepower 230-volt motor of 600/1,800 rpm and a speed regulation of 20 per cent at the high speed. It is interesting to note that the flux weakening due to armature reaction is practically independent of the speed setting as evidenced by the bending of the three curves at 300 per cent load.

Controllers for motors with speed ranges greater than two to one are provided with a field relay in order to avoid too long an accelerating time particularly when used with fans of high inertia. The field relay is usually of the fluttering type.

Overload Protection

Each motor is provided with overload and short circuit protection. In line with well-established practice the overload relay is made part of the controller, while short-circuit protection in form of feeder breakers is located on the distribution board.

Protection of Continuously Rated Motors. Overload protection of these motors is usually obtained by means of a thermal relay set at 115 to 125 per cent of full

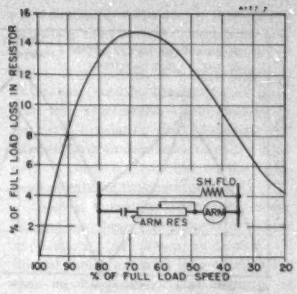


Figure 7. Resistor loss for armature speed control

load. Its time constant should be long enough to permit starting of the motor without tripping even though the starting time is long and the current surges are high.

In view of the high ambient temperatures encountered in engine rooms, the thermal overload relay is usually of the compensated type, that is, its calibration is made practically independent of the room temperature. Experience has shown that the noncompensated type is liable to trip under normal operation, thereby seriously interfering with the operation of the ship. A compensated overload relay is shown in Figure 9. It is provided with a special bimetal that corrects for changes in room temperature and thereby maintains the calibration practically constant.

Protection of Intermittently Rated Motors. There is a great deal of controversy as to whether overload protec-

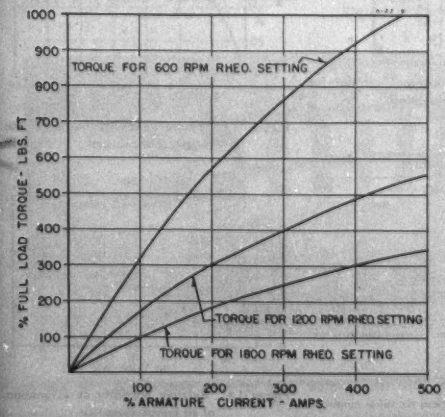


Figure 8. Starting torque of typical 20-horsepower 230-volt adjustable-speed shunt motor for different excitation and armature current

Figure 9. Compensated thermal overload relay for a-c and d-c applications

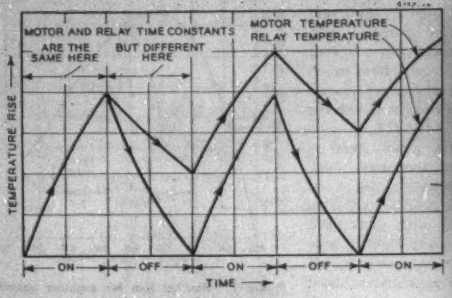


Figure 10. Heating curves showing inability of thermal overload relay to follow winding temperature of intermittently operating motor

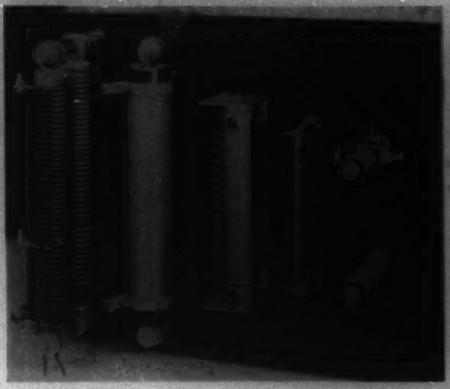


Figure 11. Various types of resistors

tion of intermittent motors by means of a thermal relay is practical. It is admitted that in order to be satisfactory such a relay should have the same time constant as the motor, that is, their temperatures should vary at the same rate when subject to various heating and cooling cycles.

This is a condition that is most difficult if not impossible to meet. Considering the fact that the time constant of motors may vary as much as three to one, depending upon their speed, ventilation, and size, it would not be feasible to design a multiplicity of relays to cover the whole range. Moreover, the co-ordinating of the time constants would be difficult since in most cases the desired information probably would not be available.

There is another important factor against matching time constants of motor and overload relay, namely, the unequal cooling of the motor while running and standing still. Tests show that with the motor standing still, the ventilation is very poor so that it will cool at a much slower rate than it heated during the running period.

Figure 10 shows that for intermittent operation the motor temperature will rise gradually above the relay temperature so that the motor is not protected even though the two time constants are matched while the motor is running.

For this reason, intermittently rated motors are protected by instantaneous overload relays set to trip at 200 to 300 per cent. They are intended to operate in case of emergency only, such as flash-over of commutators or fouling of the anchor.

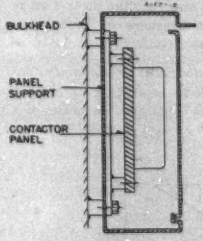


Figure 12. Typical drip-proof cabinet for bulkhead mounting

There is, however, the possibility of providing overload protection by means of thermoguards attached to the motor winding, thereby measuring motor temperature directly and stopping the motor when the temperature reaches a dangerous value.

Overload protection for capstans and windlasses is obtained with an instantane-

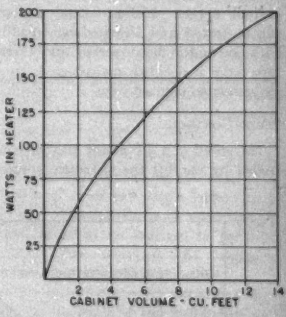


Figure 13. Heater capacity required for waterproof cabinets

Table II. Resistor Classification for Various Applications

Application	Duty	Resistor Class	Duty Cycle Sec On	Duty Cycle Sec Off
Starters below 40 hp	Starting	116	5	75
Starters above 40 hp	Starting	136	10	70
Windlass	Speed regulating	174DJ*	15	15
Capstan	Speed regulating	174J†	15	15
Cargo winch	Speed regulating	164D‡	15	30
Cable reel	Speed regulating	164	15	30
Boat hoist	Speed regulating	164	15	30

* Dynamic breaking and jamming protection with 125 per cent current for 5 minutes. Continuous running on last point lowering.

† Jamming protection with 125 per cent current for 5 minutes.

‡ Dynamic breaking in lowering direction.

The capacity of the resistors is based on good natural ventilation with not more than six tubes mounted on top of each other unless special baffles are provided.

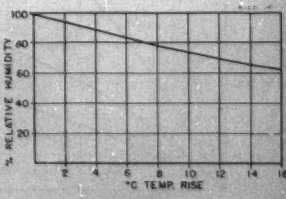


Figure 14. Relative humidity as a function of air temperature rise

Figure 15. Typical waterproof cabinet for deck application

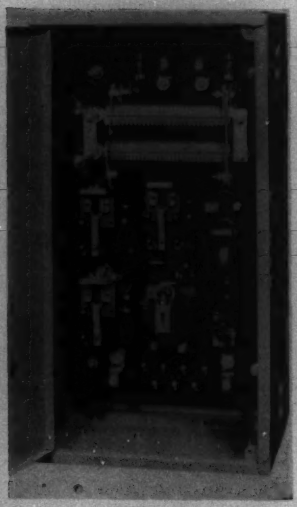


Figure 16. Typical drip-proof under-deck controller

ous jamming or step-back relay which inserts resistance in the armature circuit and reduces the stalled current to about 125 per cent rather than stopping the motor completely. This is done to maintain the tension in the anchor chain or the hawser while the ship is being warped or getting under way.

Resistors for Starting and Speed Regulating Duty

Practically without exception these resistors are of the nonbreakable and noncorrosive ribbon type using a nickel or chromium steel alloy suitable for 500–600 degrees centigrade continuous duty.

The maximum permissible temperature rise of a resistor depends a great deal on its location. When mounted in a controller cabinet, it is not desirable to exceed 365 degrees centigrade rise because it is close to apparatus with organic insulation.

However, it is satisfactory to go as high as 500 degrees centigrade rise when the resistors are mounted separately and are spaced sufficiently from other equipment to avoid undesirable heat transfer.

The tap or terminal is an important design detail of the resistors. Depending upon the design of the resistor, the terminal is either clamped, silver-soldered, or welded to the resistor ribbon. Any of these methods is satisfactory, although the welded terminal may be preferable, particularly for higher temperatures.

In order to insure a stable and permanent resistor connection, the latter must stay tight. Only in this way is it possible to keep the oxides away from the points of contact and maintain a metal-to-metal contact.

Two factors have to be considered when designing resistors for starting or regulating duty, namely, resistance and capacity. The selection of starting resistors is relatively simple since both factors are given by the number of steps and the accelerating time. Resistors for speed regulating duty, however, are more difficult to determine since the duty cycle depends a great deal on the judgment or habit of the operator.

Based on operating experience, resistor designs have been established for various applications, as shown in Table II. Special controllers with long accelerating time or heavy-duty cycle require, of course, more resistor capacity.

Controller Enclosures

Practically without exception, controller cabinets are built of structural steel in order to secure maximum strength and minimum weight at low cost. This applies to drip-proof as well as waterproof enclosures.

Designs for drip-proof cabinets are fairly well standardized. The contactor panel is mounted on rigid panel supports which, in turn, are bolted directly to the bulkhead as shown in Figure 12. This forms a strong mounting arrangement and permits a relatively light enclosure. Floor mounted drip-proof cabinets consist of the usual angle iron frame with removable sides and back to permit ready access to the apparatus. Ventilation of cabinets is usually obtained by means of louvers arranged in the side of the cabinet. This limited ventilation is sufficient for small losses such as caused by magnet coils. Larger losses, such as produced by speed regulating resistors,

Figure 18. Waterproof manual controllers for deck auxiliaries

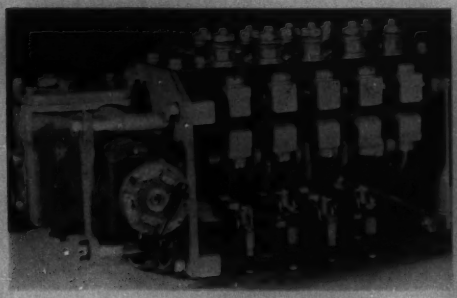
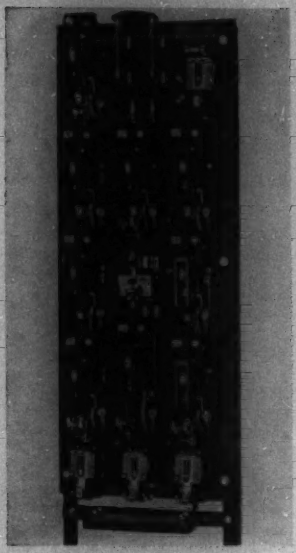
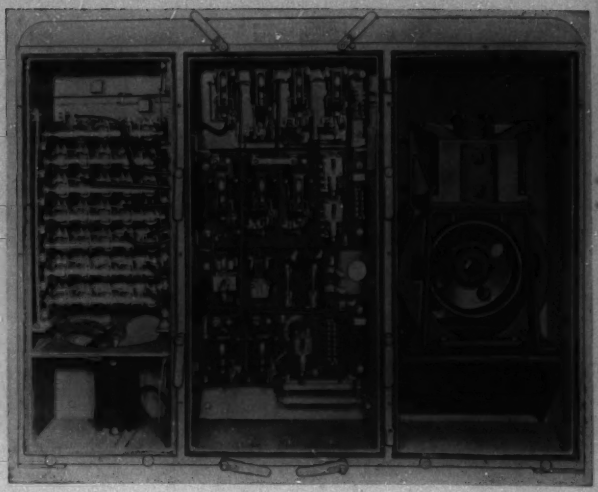


Figure 17. Accelerating drum for large motor starter with many steps



(A)

(B)



(C)

Figure 19. Magnetic controllers for deck auxiliaries

A. Open type
B. Drip-proof type
C. Waterproof type

require enclosures with raised top to permit better circulation of air.

Waterproof cabinets for deck mounting have to be made strong enough to withstand the impact of green water and to guard against corrosion eating through the walls in a relatively short time.

Corrosion of deck controllers is difficult to prevent because of condensation resulting from breathing action. The highly saturated air inside the cabinet is heated up to 50–60 degrees centigrade during a hot day and therefore, can hold considerable moisture. During the night this air is cooled off, and thus is unable to hold the water which is deposited on the inside surface, and finally collects at the bottom of the cabinet. This process is going on day after day so that under unfavorable conditions a sizable amount of water may collect in the cabinet, rendering the air so damp that even the best finish will break down after a while. There are two effective means of minimizing this corrosion. One consists in providing heaters inside the cabinet to keep the air always above the dew point. The watts required for this purpose can be determined from Figure 13. Experience has shown that a temperature rise of the air inside the cabinet of about 10 degrees centigrade is sufficient to keep the cabinet dry. The reduction of relative humidity by heating the air is illustrated in Figure 14.

An additional improvement is obtained by providing a check valve at the bottom of the cabinet to drain any possible water and to provide some circulation of fresh air. Actual tests in the field have shown that a considerable improvement is obtained with surprisingly small openings.

It cannot be emphasized too much to provide substantial bolts not less than 3/8 inch diameter for mounting of doors or covers. Sizes below that will be twisted off when trying to force a corroded thread. Doors that have to be opened very readily sometimes are equipped with locking dogs as illustrated in Figure 15. They have to be made substantial enough to withstand rough handling when covered with ice.

Controller Assemblies

It is not the purpose of this paper to give a detailed description of the various applications. Rather than do this it is proposed to show some typical controllers which illustrate the lastest design trends.

Underdeck Controllers

Figure 16 shows a typical three-step starter for a 25-horsepower motor. All controller components are mounted in front of the panel to permit ready inspection and removal of parts if necessary. Studs with solderless lugs are arranged

top and bottom for external cables, the wiring of which is facilitated by detachable and standardized lead plates of ample size. Whenever possible, the push button is mounted on the starter door to obtain a unit assembly and to reduce wiring at the shipyard to a minimum.

Large starters of high-current capacity requiring many starting steps very often are provided with a motor-operated accelerating drum as per Figure 17, which combines one line contactor and all accelerators in one single and compact unit. The spring-closed cam-opened switch units are provided with silver tips and cut out the starting resistor in predetermined intervals. The speed of the pilot motor is adjustable within a one to two speed range.

Controllers for Deck Auxiliaries

Manual as well as magnetic controllers are provided for winches, capstans, and windlasses. Manual controllers as shown in Figure 18 are limited usually to smaller motors not exceeding 30 horsepower at 230 volts or 15 horsepower at 115 volts, because experience has shown that maintenance is excessive for current ratings above these values.

Magnetic controllers are being supplied with open, drip-proof, or waterproof unit construction as shown in Figures 19A, 19B, and 19C. There has been a great tendency in recent years to favor the unit construction, particularly for cargo winches, since it reduced the installation work on the part of the shipyard to a very minimum. Its possible weakness is maintenance at sea, particularly in bad weather, although experience so far has been very satisfactory.

Figure 20. Two views of typical waterproof master switch for deck controller

Master switches are invariably of the waterproof construction, either cast or sheet steel and with an offset in the handle movement to provide a positive stop in the off position. A safe-on auxiliary switch is also provided to permit shutting down the control circuit when the equipment is not in operation. See Figure 20.

Very often it is preferred to make the master switch spring returned to obtain the so-called "dead man's feature" and to make sure that the motor cannot stay energized and accidentally burn out while the operator has "gone out for lunch." A master switch of this type is illustrated in Figure 21. Its lever is arranged so that the switch can be operated conveniently either with the stevedore standing beside the controller or sitting on it. This latter feature is desirable particularly for cargo handling where operation extends over many hours.

Figure 21. Waterproof master switch with spring-returned handle and seating facility for operator

Limitation of space does not permit discussion of special features required for different applications. Whatever control functions, however, are provided, emphasis should be placed on simplicity of design to obtain the desired results with a minimum amount of apparatus.

A New Approach to Probability Problems in Electrical Engineering

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THE PROBABILITY of simultaneous occurrences of events for which the individual rate of occurrence is known can be determined by the well-known binomial law. This law states that if n events have each a probability or rate of occurrence p, then the probabilities that 0, 1, 2, 3, etc., of the n events occur simultaneously, are given by the consecutive terms of the binomial function $[p + (1-p)]^n$. Therefore, the probability that r out of the n events occur simultaneously is

$$P_r = \frac{n!}{r!(n-r)!} p^r (1-p)^{n-r} \tag{1}$$

Applied to the probable frequency of simultaneous occurrences, this expression merely says that if each of the n events occupies a fraction p of the period of time under consideration, say a fraction p of a year, then the simultaneous occurrences of r events occupy a fraction P_r of the period under consideration. However if P_r were found to be 1/52 according to the binomial law, then it would be known only that in a year the simultaneous occurrence of r out of the n events would occupy in the average a period of one week. It is not known, however, whether this simultaneous occurrence does happen once a year with a duration of one week, or once every two years with a duration of two weeks, or seven times a year with an average duration each time of one day.

It is obvious that knowledge of the duration and intervals between overlapping events can be of considerable importance in many practical cases. In problems of congestion, such as in telephone operation, not only the probability of the use of r out of n available channels is of interest, but also the average duration and frequency of such an occurrence. Similar problems arise in connection with intermittent use of electric power, such as by welding apparatus and elevators. In statistical problems of unavailability of equipment, average length and average intervals between occurrences of unavailability may be important, such as in cases of outages of lines, transformers, or generators of electric utilities.

The equations presented in the following, which apply to a variety of problems are based on an extensive analysis and on enumerations of a great variety of cases. The equations were found to be correct also for limiting or borderline cases. The methods of analysis and derivations of the equations are not presented, as they would require too much space and exceed the scope of this paper. For the same reason, discussion of some of the purely mathematical implications and extensions of these equations are omitted.

Special Case

Starting with the most simple case, assume that each of n events has a rate of occurrence $p = t/T$ so that each event occurs once in a period of T units of time and lasts each time t consecutive units of time. Further, be it assumed that the starting points of the events can change only in steps of multiples of the unit of time selected. Then the average duration, or overlap, of r simultaneous events out of n, expressed in the selected units of time is

$$t_r = \frac{T\frac{n!}{r!(n-r)!}t^r(T-t)^{n-r}}{\left\{T\frac{n!}{r!(n-r)!}t^r(T-t)^{n-r} - T\frac{n!}{r!(n-r)!}(t-1)^r[(T-t)-1]^{n-r}\right\}} \tag{2}$$

or simplified,

$$t_r = \frac{t^r(T-t)^{n-r}}{t^r(T-t)^{n-r} - (t-1)^r[(T-t)-1]^{n-r}} \tag{3}$$

From a standpoint of statistical mathematics, the numerator of equation 2 is the sum of all possible durations of the r-fold simultaneous events and the denominator is the sum of all repetitions of such r-fold simultaneous occurrences.

In terms analogous to the binomial law, the average overlaps may be expressed by the expansion of the function

$$\frac{[tx+(T-t)]^n}{[tx+(T-t)]^n - [(t-1)x+(T-t-1)]^n} \tag{4}$$

(Here x is merely a "generating function" for convenient identification of terms corresponding to exponent r on x. Only the coefficients are of interest.) The overlap t_r is then the ratio of the coefficients of x^r which occur in numerator and denominator. This ratio is identical with equations 2 and 3.

As stated before, equations 2 and 3 assume that the start of the events can shift only in multiples of the unit of time chosen. Of course, these steps can be made as small as desired by choosing a small enough time unit. The restrictions of unit steps can be completely removed if we substitute pT for t in equation 3 and pass to the limit. We then obtain for the overlap duration, t_r expressed as a fraction of the entire period T under consideration.

$$\lim_{T\to\infty} \frac{t_r}{T} = \frac{(1-p)p}{r+p(n-2r)} \tag{5}$$

With P_r from equation 1 and t_r from equation 3 or 5, we get the average interval T_r between r-fold simultaneous events by

$$T_r = t_r/P_r \tag{6}$$

The frequency of such overlaps is

$$f_r = \frac{1}{T_r} = P_r/t_r \tag{7}$$

Following is a practical application of these equations. A single-phase 60-cycle circuit is supplying 30 welders. On the average, each welder gives 25 random current impulses per minute to the circuit. Each impulse lasts on the average 5 cycles. What are the average durations and frequencies of the various possible amplitudes of impulses? Here $t = 5$ cycles, $T = 1/25$ minute or 144 cycles, and $p = 5/144$. The durations and frequencies of the impulses of various amplitudes, as calculated by equations 5 and 7, are given in Table I.

Values of currents up to six times the rating of one welder are quite frequent, indicating the possibility of serious voltage flicker. From the data in Table I, it is simple to calculate the equivalent current in the cable which produces the same heating of the conductor as the various current impulses.

More General Case

In the case discussed, all individual events had the same rate and duration of occurrence. Now consider the case where each of the n events occurs again once in

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Table I

r, Number of Welders Overlapping in Operation	t_r, Average Duration of Overlap in Cycles	t_r, Frequency of Overlap Per Minute
0	4.63	269
1	2.45	548
2	1.664	423
3	1.259	187.3
4	1.010	56.5
5	0.847	12.63
6	0.728	2.2
7	0.638	0.309
8	0.568	0.036
9	0.512	0.0035

the period T, but the duration of each event is different. The duration t has different lengths $a, b, c, \ldots$ for the different events and the probabilities $p = t/T$ have consequently different values. Then, assuming first that each event can shift only in steps of multiples of the time unit, the average duration or overlaps of r-fold simultaneous occurrences, expressed in the units of time chosen, is given by the ratios of the coefficients in the numerator and denominator of the expanded function 9, that is,

$$t_r = \frac{gx^r}{hx^r} \tag{8}$$

where g and h are the coefficients of x^r in the numerator and denominator, respectively, of the expanded function

$$\frac{\Pi[tx+(T-t)]}{\Pi[tx+(T-t)]-\Pi[(t-1)x+(T-t-1)]} \tag{9}$$

Here Π signifies the products of the terms in the parentheses, with t assuming all the different values $a, b, c, \ldots$. Written differently and assuming only three events with durations a, b, and c, the average duration of the various overlaps are given by the ratios of the coefficients of x^r in the numerator and denominator of the function

$$\frac{[ax+(T-a)][bx+(T-b)][cx+(T-c)]}{\begin{aligned}&[ax+(T-a)][bx+(T-b)][cx+(T-c)]-\\&[(a-1)x+(T-a-1)][(b-1)x+\\&(T-b-1)][(c-1)x+(T-c-1)]\end{aligned}} \tag{10}$$

Again the steps in which the events shift can be made as small as desired by choosing the unit of time suitably small. The limitation of shift in multiples of the time units can be eliminated completely by setting

$$p_a = \frac{a}{T},\ p_b = \frac{b}{T},\ p_c = \frac{c}{T}$$

$$q_a = 1-p_a,\ q_b = 1-p_b,\ q_c = 1-p_c$$

and passing to the limit $T \to \infty$. Then the overlaps of r-fold simultaneous occurrences expressed as a fraction of the period T are given by the ratios of the coefficients in the numerator and denominator of the terms x^r of the following function

$$\begin{aligned}&\frac{(p_ax+q_a)(p_bx+q_b)(p_cx+q_c)}{(x+1)[(p_ax+q_a)(p_bx+q_b)+}\\&\qquad(p_ax+q_a)(p_cx+q_c)+\\&\qquad(p_bx+q_b)(p_cx+q_c)]\end{aligned} \tag{11}$$

which can, of course, be generalized to any number of terms $n > 3$.

As an example, assume that a distributing station of an electric power company is supplied by three lines from different sources. According to statistical data each of the three lines can be expected to be forced out of service once a year. Due to the different nature of the lines, 48 hours are required to restore the first line to service, 24 hours are required for the second line, and 12 hours are required for the third line. Then, $a = 48$, $b = 24$, $c = 12$, $T = 8{,}760$, $p_a = 48/8{,}760$, $p_b = 24/8{,}760$, and $p_c = 12/8{,}760$. The average duration and intervals of outages as calculated by equation 10 or 11 is given in Table II.

Events of Different Amplitudes

The preceding equations gave information on only the number of lines out of service. If the loads which can be carried by the three lines are different, then it may be more important to obtain information on the kilovolt-amperes out of service rather than the number of lines out of service. If the three lines of the preceding example have different load-carrying capacities, L_a, L_b, and L_c, then the average duration and intervals of loss of various amounts of kilovolt-amperes can be obtained from equation 10 by substituting x_a, x_b, and x_c for x. Then the average duration of the loss of L_a kilovolt-amperes is the ratio of the coefficients for x_a in the expanded numerators and denominators, the loss of $L_b + L_c$ kilovolt-amperes is given by the coefficients of $x_b x_c$, the loss of $L_a + L_b + L_c$ kilovolt-amperes is given by the coefficients of $x_a x_b x_c$, and so on.

Table II

Number of Lines out of Service	Average Duration of Outages in Hours	Average Interval of Outages in Years
0	2920	0.344
1	27.9	0.334
2	12.2	53.14
3	6.8	37,747

Completely General Case

Assume that an event n occurs f_n times during the period T where f_n may be different for each event. The lengths of the f_n occurrences of the event n may be all different and so may be the intervals between occurrences. The individual lengths of these occurrences may be $t_{n\alpha}$ $(\alpha = 1, 2, \ldots, f_n)$ units. The individual lengths of intervals between occurrences may be $\delta_{n\alpha} (\alpha = 1, \ldots, f_n)$ units.

Table III

Number of Channels in Use	Average Length of Overlap in Seconds	Frequency of Overlap Per Second
3	1.02	0.206
2	0.88	0.501
1	0.74	0.392
0	0.62	0.097

Let

$$\sum_{\alpha=1}^{\alpha=f_n} t_{n\alpha} = \theta_n$$

and

$$\sum_{\alpha=1}^{\alpha=f_n} \delta_{n\alpha} = \Delta_n$$

In other words θ_n is the sum of the lengths of the f_n different occurrences for the event n, and Δ_n is the sum of the intervals between occurrences. Therefore,

$$\theta_n + \Delta_n = T$$

Then, assuming again that the events can shift only in multiples of the unit of time, the average duration or overlap of $0, 1, 2, \ldots n$, simultaneous occurrences is given by the ratios of the coefficients of the various terms x^r in the expansion of the function.

$$\frac{\prod_{n=1}^{n}[\theta_n x+\Delta_n]}{\prod_{n=1}^{n}[\theta_n x+\Delta_n]-\prod_{n=1}^{n}[(\theta_n-f_n)x+(\Delta_n-f_n)]} \tag{12}$$

It is of special interest that in the numerator as in the denominator, the individual lengths of occurrences for each event and the order of occurrences have no effect on the result, but only the sums of the lengths of occurrences and of the intervals and the frequency of occurrence, or number of repetitions are of importance. This fact, of course, simplifies the application of this general formula considerably. Finally, we can remove the restriction of shift of events in multiples of the time unit by substituting $p_n T$ for θ_n and $q_n T$ for Δ_n and, furthermore, setting $p_n/f_n = v_n$ and $q_n/f_n = w_n$.

When we pass to the limit $T \to \infty$ we obtain for the duration of the average

overlaps expressed as fractions of the period T,

$$\lim_{T\to\infty}\frac{t_r}{T}=\frac{\left(\prod_{r_n}^{r}\times\prod_{w_n}^{n-r}\right)}{\sum\left(\prod_{r_n}^{r-1}\times\prod_{w_n}^{n-r}\right)+\sum\left(\prod_{r_n}^{r}\times\prod_{w_n}^{n-r-1}\right)} \quad (13)$$

where the superscripts on the product symbols designate the number of terms in the product. Each double product contains each index of one to n not more than once. The summations are taken over all different combinations of n subscripts or indices in two groups of r and $(n-r)$, each in the numerator, and of $(r-1)$, and $(n-r)$, and of r, and $(n-r-1)$ each in the denominator corresponding to the double products.

If all values of v_n are identical and, consequently, all values of w_n are identical, equation 13 reduces to

$$\lim_{T\to\infty}\frac{t_r}{T}=\frac{vw}{mw+(n-m)v} \quad (14)$$

If $f=1$, then $v=p$ and $w=q=1-p$, and equation 14 reduces to equation 5.

As an example of the general case, assume that of three available channels the first is in use once in the period T of 10 seconds and the duration of use is 5 seconds. The second channel is in use twice in each period T of 10 seconds and the two durations of use, 2 and 5 seconds, occur with equal frequency. The third channel is in use three times in each period T of 10 seconds and the equally likely durations of these three uses are 1, 2, and 3 seconds, respectively. Then the average durations and frequencies of overlaps, as calculated by equation 12, are given in Table III.

This example, admittedly artificial to illustrate the general formula, is typical of problems which can occur in telephone practice and in other fields of electrical engineering. Still further generalization is possible, and has been carried out though not elaborated here, along two general lines. First, it is possible to work out a method—but not a formula—to express the duration and interval between recurrences of "r or more" simultaneous occurrences and to further extend it to "w or more" kilovolt-amperes, say, when individual events are of unequal capacity. Secondly, it is possible to determine the deviations from the mean of the durations and intervals given by the above formulas.

The methods and equations as outlined have helped considerably in solving practical problems which could not be solved by equations previously available.

Excitation, Control, and Cooling of Ignitron Tubes

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APPLICATION DATA for mercury pool tubes or tanks must include information covering rectifier capacity, control characteristics, excitation requirements, losses, cooling requirements, and other essential characteristics.

The factors affecting rectifier capacity, the relations between these factors, and the procedure for specifying rectifier capacity have been set forth in a companion paper. This paper presents a description of the excitation, control, and cooling characteristics of typical mercury-arc tubes of the ignitron type and outlines a procedure for specifying these characteristics, together with the limitations and operating requirements which must be considered.

Excitation

The excitation system must establish and maintain the conditions required for arc conduction. To do this it must perform three functions:

1. Start a cathode spot on the cathode pool.
2. Maintain the cathode spot.
3. Extend the ionization to the anode region.

Ignitors

In rectifiers of the ignitron type, a cathode spot is started each cycle by the ignitor. In order to perform the starting function successfully, the ignitor must be supplied with sufficient energy to assure reliable operation. The instantaneous volt-ampere requirements of the ignitor depend upon its construction, composition, and treatment. Individual ignitors vary in resistance and starting characteristics because of small differences introduced during manufacture or operation. In order to assure reliable ignitor operation, definite specifications have been set up for ignitor performance. Acceptable ignitors must fire at peak voltages and currents within the specified maximum values.

The ignitor excitation requirements are best described by a volt-ampere characteristic of the type shown in Figure 1. The "minimum" curve gives the instantaneous volt-amperes that this excitation circuit should deliver. It must be understood that an ample margin should be allowed between the "minimum" curve and the maximum volt-amperes required to fire acceptable ignitors. The "maximum" curve indicates the highest value of instantaneous volt-amperes that the firing circuit may deliver without damage to the ignitor or seal assembly.

A wide variation in the resistance of individual ignitors is permissible, and the dotted curves show typical characteristics for ignitors having resistances ranging from 2 to 100 ohms. The peak short-circuit current and open-circuit voltage indicated by the solid curves are particularly useful in specifying the excitation circuit requirements. Further limitations and requirements of the ignitors are indicated in Table I.

Auxiliary Anodes

In order to minimize the power consumed by the ignitors and also the physical size of the firing circuit components the ignitor volt-amperes are usually sustained for only a few electrical degrees (from 10 to 25 degrees in most circuits). Auxiliary excitation or relieving anodes, therefore, are used to perform the following functions:

1. Maintain the cathode spot for the required period. Many circuits require that excitation be maintained for 90 degrees in order to assure reliable operation at light load.
2. Furnish additional energy for ionization of the arc space.
3. Reduce the duty on rectifying elements in the firing circuit by providing a shunt path.

Table I. Ignitor Limitations and Requirements

Maximum rms current allowed, amperes	15
Maximum avg current allowed, amperes	3.0
Maximum instantaneous inverse voltage allowed, volts	5

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These auxiliary anodes may be located either in the open arc path or in a shielded space adjacent to the cathode pool. They are usually excited from a sinusoidal source. Typical wave forms are shown in Figure 2.

The inverse voltage applied to the excitation anode must be held to a low value in order to limit the positive ion bombardment and avoid arc-backs. The maximum allowable inverse voltage depends upon the amount of shielding around the excitation anode and the time of application of the inverse voltage, that is, whether the inverse voltage is applied during the main anode conduction or during the main anode inverse period. By proper phasing

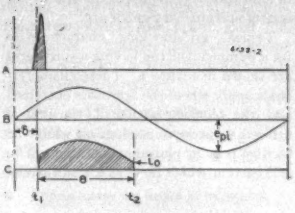

Figure 2. Excitation anode wave forms

A—Ignitor current
B—Excitation anode voltage
C—Excitation anode current

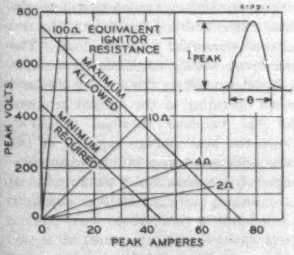

Figure 1. Ignitor instantaneous volt-ampere requirements

Pulse duration $\theta = 10$ to 15 degrees at 25 to 60 cycles

of the excitation anode voltage with respect to the ignitor firing point, the excitation anode conduction period may often be fixed so that inverse voltage is applied to the excitation anode only during the main anode inverse period. Where this is not possible, some means, such as a rectifying element), must be provided to limit the inverse voltage which may be applied. Further limitations and requirements are indicated in Table II.

Grids

While the grids are also a part of the excitation system, in that they help to establish the conditions for conduction, this is only incidental to their control action. Their characteristics are covered in the section on control.

Control

In an ignitron, control of conduction may be obtained by means of either ignitors or grids. The ignitor provides the only means of control in many small tubes which are built without grids. In such tubes, the ignitor usually provides effective control over the full range of operation. However, most larger tubes are equipped with one or more grids.

The primary function of the grid is to control both the arc phenomena in the neighborhood of the anode and the starting of anode conduction. While the establishment of suitable arc conditions at the anode is essential to the action of the rectifier and affects the rectifier capacity directly, the control function of the grid is the more important from an application standpoint.

The grid action depends directly upon the electronic processes taking place in the rectifier throughout the cycle. These are well illustrated by the oscillographic observations shown in Figure 3. These observations were made on a pumped ignitron operating in a six-tank unit at $E_{d_0} = 1{,}294$ volts and $I_d = 2{,}000$ amperes load current. In order to facilitate analysis of the action, the grids were excited from a rectangular voltage wave of 125 volts peak through 500 ohm resistors.

Referring to Figure 3, main anode conduction starts at time t_0 with a positive grid current. At time t_1, before the end of conduction, the voltage applied to the grid circuit is made negative. The grid potential remains substantially unchanged although the grid current is reversed. The positive ion current collected by the grid is limited only by the resistance of the grid circuit. Main anode conduction ends at time t_2. However, the grid current is sustained as the grid continues to collect positive ions from the residual ionization. As deionization continues, the intensity of ionization finally, at time t_3, falls below that required to sustain the full positive ion grid current, and the grid current then falls off along a

Table II. Excitation Anode Limitations and Requirements

Maximum rms current allowed, amperes	10
Maximum avg., current allowed amperes	5
Minimum instantaneous current required to maintain cathode spot, amperes	3
Maximum peak inverse voltage allowed during conduction, volts	25
Maximum peak inverse voltage allowed during inverse, volts	150

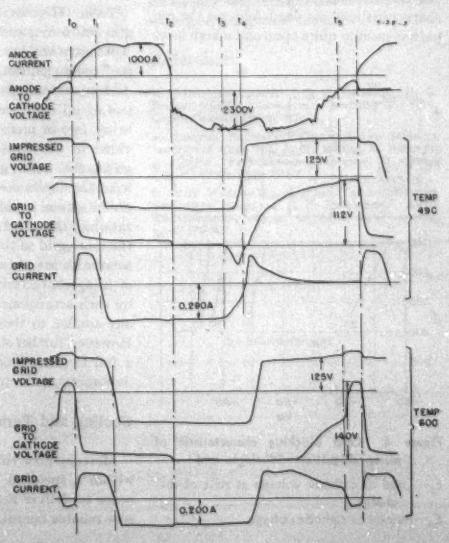

Figure 3. Grid characteristics on pumped ignitron with single grid

decrement curve as deionization progresses. At time t_4, the voltage applied to the grid circuit again becomes positive. The grid now collects electrons and since these are more mobile than the positive ions and can be drawn from the entire arc space, the grid current again reaches the limiting value fixed by resistance. However, the deionization process continues and this current also falls off on a decrement.

Late in the unverse cycle, the main anode becomes positive at time t_4. Since the rectifier is operating with phase control and the ignitor has not yet fired, conduction does not begin. However, the grid again collects ions as it is made negative with respect to the anode. This action is quite pronounced when operating at 60 degrees centigrade temperature.

Many conclusions regarding the action may be deduced from these observations. Some of these are as follows:

1. Ionization persists throughout the inverse cycle.
2. The deionization time is a function of the control temperature.
3. The action of the grid assists the decay of ionization.
4. The grid shields the anode from the ionization which persists in the arc path during the inverse cycle.

Grid Characteristics

Most ignitron tubes with a single grid have a negative grid characteristic, that is, require a negative grid potential to prevent conduction. This negative grid characteristic is obtained because the arc path is usually quite open and a high level of ionization is provided at the grid by the ignitor and auxiliary anode arc.

Typical grid-blocking characteristics for a pumped ignitron having a single grid are shown in Figure 4. These characteristics apply where the ignitor is energized and the blocking action of the grid is utilized to prevent conduction while the rectifier is being placed in operation. The grid current which flows as a result of the ionization produced by the ignitor and excitation anode is shown in Figure 5.

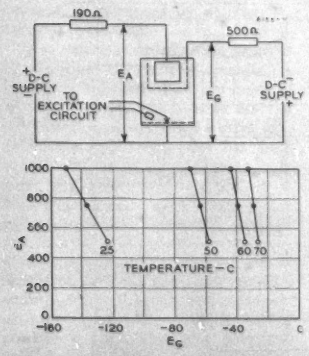

Figure 4. Grid blocking characteristic of pumped ignitron with single grid

E_g—Grid to cathode voltage at start of discharge

E_a—Anode to cathode voltage

Table III. Grid Limitations and Requirements

Minimum grid resistance allowed, ohms	500
Maximum grid resistance allowed, ohms	5,000
Maximum inverse voltage allowed during conduction, volts	150
Maximum inverse voltage allowed during inverse, volts	300
Minimum positive voltage required to fire, volts	50
Maximum positive voltage allowed, volts	300

The grid characteristics, when operating with phase control, are similar to those for blocking, except that the presence of the ionization from the conduction of the preceding cycle increases the negative voltage required on the grid to prevent arc-through, or loss of control. The slow deionization of a single grid tube is shown clearly in Figure 3. For this reason, a single grid does not provide effective control over a wide range of temperature and ionization. A wider range of control may often be obtained by the ignitor than by the grid in a single grid tube.

Table III gives a further list of typical grid limitations and requirements.

Where a wide range of phase control is required to obtain blocking action from no load to fault currents, full phase control at all loads, and accurate timing of firing, two or more grids are usually provided in the ignitron tube. With two grids, the outer grid shields the inner from the ionization in the arc path and permits more rapid and complete deionization of the space around the anode and the inner grid so that better control characteristics are obtained. A wide variety of firing characteristics may be obtained by such arrangements. These are generally similar to those for the single grid. However, further studies are necessary for a full treatment of their characteristics, limitations, and requirements.

Cooling and Temperature Control

Mercury-pool tubes must be operated within a specified temperature range in order to deliver rated power output, assure reliable operation, and prevent damage during faults. The temperature also affects the rectifier efficiency since the arc losses are a function of temperature.

The temperature regulating equipment which is provided for the purpose of establishing the desired temperature conditions must perform the following major functions:

1. Remove the heat produced by the arc losses.
2. Maintain the desired control temperature.
3. Maintain the desired temperature gradient on the anode seals.
4. Minimize corrosion.

Arc Losses

Most ignitron tubes have an arc drop ranging from 15 to 25 volts. The losses are approximately proportional to the load current although the arc drop increases somewhat with the load. The maximum cooling requirements are usually determined by the arc loss obtained when operating at the current required for the two-hour overload condition. Since the heat storage capacity of the usual tube structure is equivalent approximately to a thermal time constant of 15 to 30 minutes, overloads of short duration,

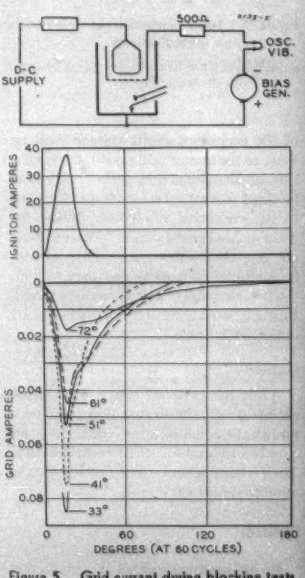

Figure 5. Grid current during blocking tests

Anode to cathode voltage = 0
Grid to cathode voltage = −300 volts
Temperature as shown

such as one minute, need not be considered in the determination of the cooling requirements.

Figure 6 shows a typical arc drop characteristic for a pumped ignitron operating in a unit of six tanks with a double-Y connection. This represents the usual mode of operation where $P = 3$, the conduction period is $(120° + u)$, and the peak tube current is three times the average tube current. An alternate connection which is sometimes used is the fork where $P = 6$, the conducting period is $(60° + u)$, and the peak tube current is six times the average tube current. The arc drop in this case will be higher because of the increased peak current and the losses, therefore, will be greater. Tests on two units show that the losses at the same load are increased approximately eight per cent over those obtained when operating double-Y. A similar correction factor, but having a different value, may be determined for other modes of operation.

Cooling

The majority of power rectifiers are cooled by water which is passed through suitable water jackets. Two general systems of water cooling may be employed. One is the direct raw water-cooling system in which water is taken from a suitable supply, passed directly over the cooling surfaces of the rectifier, and discharged. The other is the heat-exchanger cooling system in which a coolant is passed over the cooling surfaces of the rectifier, then cooled in a heat exchanger and recirculated.

Direct raw water cooling requires the least amount of equipment and, therefore, frequently is used on small units ranging from 75 kw to 300 kw. In such systems, tubes must operate over a wide temperature range with varying water flow. In order to conserve water, the tube water jackets usually are connected in series.

Heat-exchanger cooling systems are used for all the larger rectifiers where it is desired to operate the tubes at the optimum temperature and utilize their full capabilities. Pertinent information necessary in applying a heat exchanger to a rectifier unit is as follows:

1. Type and design of rectifier.
2. Water flow in gallons per minute.
3. Pressure drop through water jacket, in pounds.
4. Approximate arc losses in kilowatts.

Anode Heaters

It is necessary to maintain a temperature gradient at all times from the anode

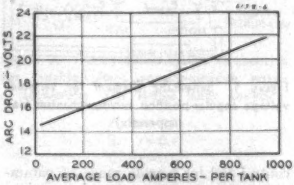

Figure 6. Typical arc-drop characteristic for pumped ignitron

and grid seals to the tank, so as to prevent the condensation of mercury on the seal insulators. On equipment employing sealed tubes, with direct raw water cooling, usual service conditions are generally such that no heaters are required. Where sealed ignitrons operate under unusual service conditions which are unfavorable, anode heaters must be provided. Anode heaters generally are required on all pumped ignitrons. These heaters range up to 350 watts, depending upon the size of the tube and the service conditions.

Corrosion

The prevention of corrosion in rectifier cooling systems, involves two considerations, one, a proper choice of metals which come in contact with the water, and second, the control of the chemical constituents of the coolant. The sealed tubes employ stainless steel for the vacuum tank in order to insure vacuum tightness. A complete corrosion-resistant water chamber is readily obtained by providing water jackets of the same material. The stainless steel construction of sealed tubes makes them suitable for use in direct raw water cooling systems. Pumped rectifiers employ vacuum tanks made of boiler plate steel. They must be proved with copper cooling coils for use in direct raw water-cooling systems.

For heat exchanger systems, where a recirculating coolant is used, the materials in the associated piping which is connected to the rectifier should consist of malleable iron pipe and fittings. It is good practice that the recirculating water be treated with sodium chromate ($Na_2 - CrO_4$), using either distilled or an approved raw water.

Conclusions

The factors which must be considered in the application of mercury-pool tubes and the design of rectifier units have been described. Also a procedure for specifying their characteristics, limitations, and requirements has been outlined.

A full knowledge of the characteristics, limitations, and requirements of the ignitron tube is essential to the design of a successful and economical rectifier unit inasmuch as the auxiliaries required for excitation and temperature control are an important part of the unit.

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Dimensionless Analysis of Servomechanisms by Electrical Analogy

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THE MECHANICAL transients analyzer[1,2] provides a fast and simple method of obtaining the complete solutions to the performance equations of servomechanisms under any type of operating condition. It has been found to be applicable to the detailed analysis of specific systems. Also, because of the great rapidity with which parameters of a basic system can be changed once that system is set up, the analyzer is admirably suited to generalized studies of various types of systems. This paper presents a general study that has been made of variable-voltage angular-position servomechanisms. The data give dominant system frequencies and damping rates for a two time delay system with simple error control and for a wide range of parameters. Similar data are presented for error control plus optimum anticipation time constants, together with other performance characteristics. Because of the many curves required for the same type of analysis of the several variations of resistance-capacitance-feedback and other forms of antihunt or damping devices, they will not be treated here.

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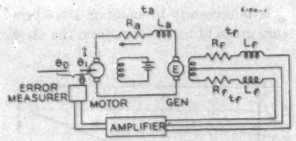

Figure 1. Schematic diagram for variable-voltage angular-position servomechanism (see appendix)

The range of parameters chosen is sufficiently wide to cover all practical types of variable-voltage servo applications. The performance of a given system or the choice of parameters for optimum performance can be quickly obtained from the dimensionless data on the curves.

Description of System Studied

A schematic diagram of the system studied, together with the definition of all parameters and the system equations, is given in Figure 1. In this system two time delays are included. One of these, t_a, can only represent the armature circuit time delay. However, if the field time delay of the system being studied is negligible, t_f can represent any other time delay back in the system. The appendix gives the dimensionless parameters upon which the generalized study is based.[3] These include the undamped natural frequency ω_n with no time delays, the ratio, r, of actual to critical damping with no time delays, and the time constants put in dimensionless form through multiplication by ω_n. In the accompanying curves, the performance solutions plotted as functions of the above parameters are actual dominant system frequencies, dominant system damping rates, and crest values of the error angle. The first two are applicable to any form of disturbance or motion to be followed. As shown in the appendix, system frequencies are put in dimensionless form by expressing them as a fraction of ω_n. Damping is given in per cent per cycle. Since a suddenly applied constant velocity is considered to be the most basic type of disturbance function for such systems, the actual solutions were obtained for this case and the crest error angles, θ_{max}, or transient overshoots, were put in dimensionless form by expressing them as a function of the steady-state error angle, θ_{ss}, for such disturbance (see appendix).

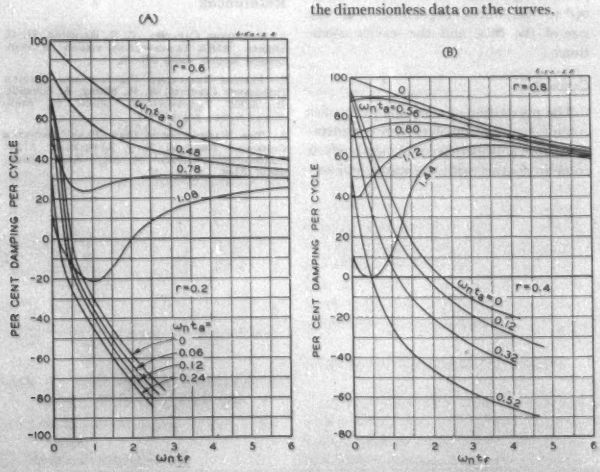

Figure 2. Dimensionless curves of per cent damping for variable-voltage (two time delays), angular-position servomechanisms with simple error control

A. $r=0.2$ and $r=0.6$
B. $r=0.4$ and $r=0.8$
C. $r=1.0$

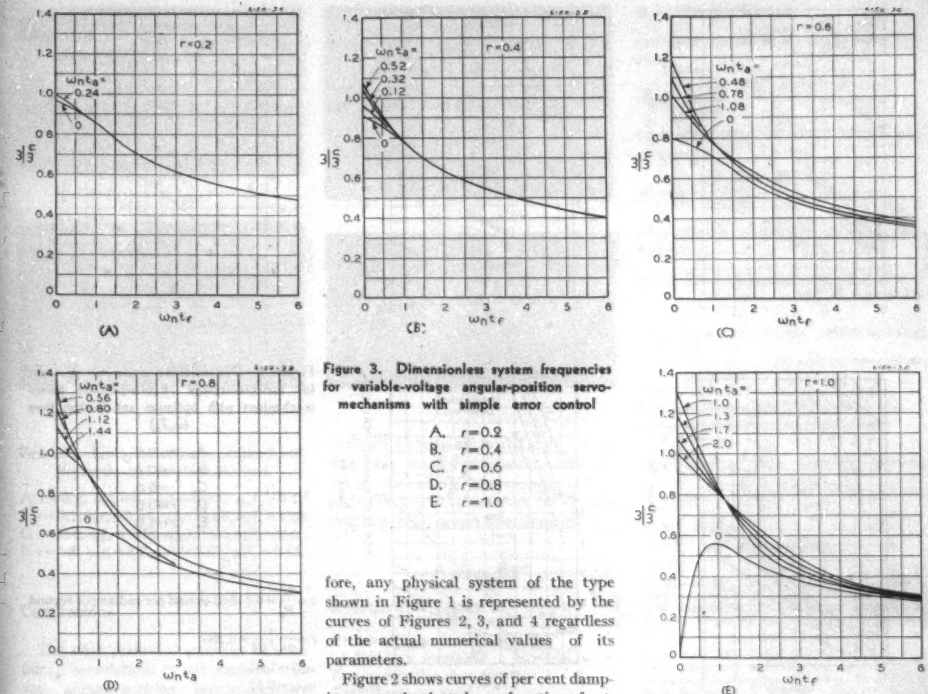

Figure 3. Dimensionless system frequencies for variable-voltage angular-position servomechanisms with simple error control

A. $r=0.2$
B. $r=0.4$
C. $r=0.6$
D. $r=0.8$
E. $r=1.0$

The method of studying such systems on the transients analyzer is discussed in detail in reference 1. The basic torque equation of Figure 1 is represented as an electric circuit with suitable circuit constants and amplifiers. The exact circuits and analogies used are given in the above reference. The complete transient solutions were observed or photographed on the screen of a cathode-ray oscilloscope. In reading and recording data either from the oscilloscope screen or the photographs, precautions were taken to obtain about five per cent accuracy. Numerous check calculations were made for the case of simple error control, all of which checked well within ten per cent. It should be pointed out that the data presented represent the equivalent of the solution of several thousand servo-equations. The greatest number of solutions would be required in obtaining the optimum anticipation which is quite simple with the analyzer.

Analysis of Data

The information presented in Figures 2, 3, and 4 is in dimensionless form. Therefore, any physical system of the type shown in Figure 1 is represented by the curves of Figures 2, 3, and 4 regardless of the actual numerical values of its parameters.

Figure 2 shows curves of per cent damping per cycle plotted as a function of $\omega_n t_a$ for different values of $\omega_n t_a$, and r equal to 0.2, 0.4, 0.6, 0.8, and 1.0. All symbols used are as defined in the appendix. In Figure 3 the ratio of actual frequency, ω, to the undamped natural frequency, ω_n, is also plotted as a function of $\omega_n t_f$ for various values of $\omega_n t_a$, and r equal to 0.2, 0.4, 0.6, 0.8, and 1.0. The data of Figure 4 were obtained by choosing an anticipation time, $\omega_n T_a$, to provide the best compromise between damping, response, and overshoot. These data give per cent damping per cycle, the ratio of maximum angular error, θ_{max}, to the steady-state angular error for a constant input velocity, θ_{ss}, the ratio of actual to undamped frequency, ω/ω_n, and the optimum value of anticipation time, $\omega_n T_a$, as a function of the two system time delays. Separate curves are given for r equal to 0.2, 0.4, 0.6, 0.8, and 1.0. Figure 5 shows photographs of some of the typical solutions obtained in deriving the curves of Figure 4. The ordinate is angular error θ, and the abscissa, time.

A study of Figures 2, 3, and 4 shows that any general conclusions drawn may have exceptions at particular points. Thus, although frequency and damping generally decrease with increase of $\omega_n t_f$, in Figure 3C, for $\omega_n t_a = 0$, frequency increases with increase of $\omega_n t_f$ up to about 1.0, and in Figure 2C, damping increases for a number of values of $\omega_n t_a$ for increase in $\omega_n t_f$ to 1.0 or better.

In order to have satisfactory performance of the simple-error type of servomechanism, it can be seen in general in Figures 2 and 3 that large values of r and small values of $\omega_n t_a$ and $\omega_n t_f$ are required. The exception to the above statement is found at values of r of 0.8 and 1.0 where it is possible to increase the damping to a satisfactory level by increasing $\omega_n t_f$, although there is a sacrifice in frequency ratio.

The use of an error rate or anticipation term in the controller usually results in a well-damped system with good frequency response when r is small and the time delays $\omega_n t_a$ and $\omega_n t_f$ are large. This is well illustrated by Figure 4 and by actual photographs of such a case, Figures 5A and B. However, for the practical range of time delays for r equal to 0.2, damping decreases for all cases of increasing time delays. Difficulty is encountered in obtain-

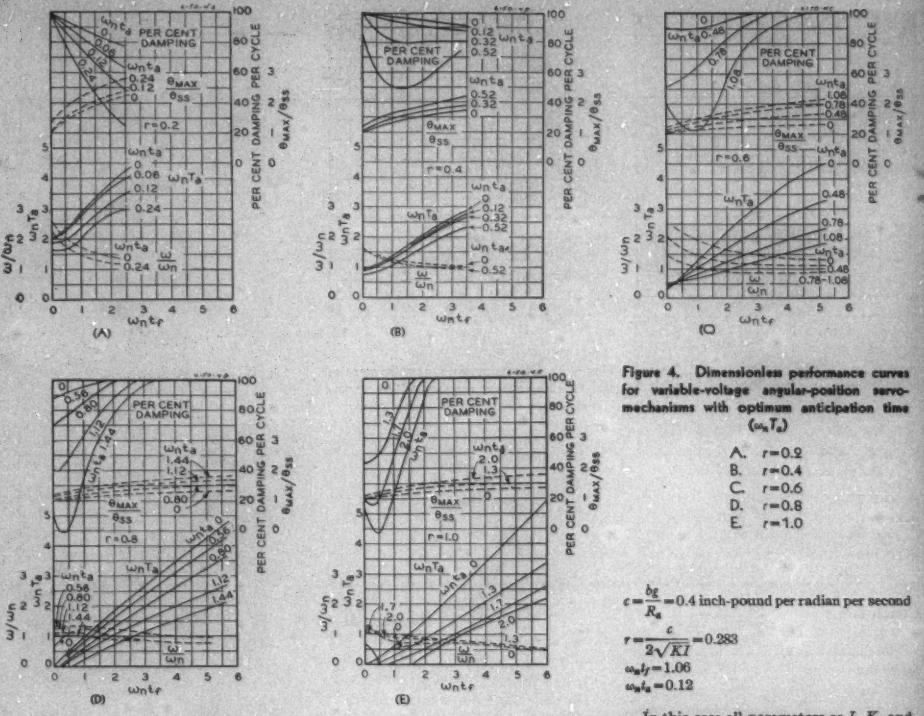

Figure 4. Dimensionless performance curves for variable-voltage angular-position servomechanisms with optimum anticipation time ($\omega_n T_a$)

A. $r=0.2$
B. $r=0.4$
C. $r=0.6$
D. $r=0.8$
E. $r=1.0$

ing sufficient damping at r equal to 0.6, 0.8, and 1.0 for large values of $\omega_n t_a$ and small values of $\omega_n t_f$. The photographic record of Figure 5C and D shows this. In Figure 5D the principal effect of anticipation is to reduce the magnitude of the oscillation with little or no increase in damping. It should be recognized immediately that this is not a common operating point, for the armature time delay is rarely even of the same order of magnitude as the field delay.

In general, the optimum anticipation time, $\omega_n T_a$, increases; the frequency ratio, ω/ω_n, decreases; and the peak ratio, θ_{max}/θ_{ss}, increases with increase in $\omega_n t_f$.

Remembering that high values of r bring correspondingly higher steady-state errors for a constant input velocity and greater power loss, the advantage of anticipatory control over the simple error control is apparent.

The curves of Figures 2, 3, and 4 have been smoothed so that some of the small kinks, caused by the large number of roots in the differential equations, have been omitted. At all points, however, the curves are well within an accuracy of ten per cent. There is no difficulty in choosing the dominant frequency in most cases. However, where a second frequency is pronounced, the ω chosen was that which corresponded to the time for the initial overshoot to first return to the steady-state angular error, θ_{ss}.

Typical Example

To clearly illustrate how easily the data in Figures 2, 3, and 4 can be used, a typical variable-voltage angular-position servomechanism problem is worked out below.

The parameter values are as follows:

$I=10^{-1}$ pound-inch-second^2
$K=5$ inch-pounds per radian
$R_a=6$ ohms
$L_a=0.10$ henry
$R_f=100$ ohms
$L_f=15$ henries
$b=4$ inch-pounds per ampere
$g=0.6$ volt per radian per second

$$\omega_n=\sqrt{\frac{K}{I}}=7.07 \text{ radians per second}$$

$$c=\frac{bg}{R_a}=0.4 \text{ inch-pound per radian per second}$$

$$r=\frac{c}{2\sqrt{KI}}=0.283$$

$\omega_n t_f=1.06$
$\omega_n t_a=0.12$

In this case all parameters as I, K, and b that are a function of shaft speed are given at the motor shaft.

Any shaft geared to the motor could easily have been used as a reference instead, as long as all the values were given at that shaft. At times this may be desirable.

Referring to Figure 4 and interpolating between Figure 4A and B for $r=0.28$ gives the following data:

Optimum $\omega_n T_a=2.0$
Per cent damping per cycle = 83
$\omega/\omega_n=1.4$
$\theta_{max}/\theta_{ss}=1.7$

Therefore, if in the actual system T_a is made $2.0/7.07=0.283$ second, the actual system will have a frequency of $1.4\times 7.07=10$ radians per second, and a maximum angular error at the motor shaft for a suddenly applied constant velocity, ω_1, of

$$1.7\times\frac{2r\omega_1}{\omega_n}=0.137\omega_1$$

The damping per cycle of the system is 83 per cent.

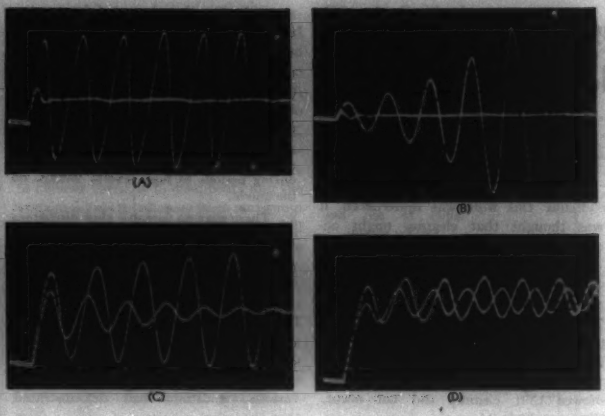

Figure 5. Typical solutions as obtained with the mechanical-transients analyzer

A. $r=0.2$, $\omega_n t_a=0$, $\omega_n t_f=0.53$, $\omega_n T_a=2.19$
B. $r=0.2$, $\omega_n t_a=0.24$, $\omega_n t_f=0.53$, $\omega_n T_a=1.64$
C. $r=0.6$, $\omega_n t_a=1.08$, $\omega_n t_f=1.06$, $\omega_n T_a=0.6$
D. $r=1.0$, $\omega_n t_a=2.0$, $\omega_n t_f=0.53$, $\omega_n T_a=0.55$

Conclusions

The data presented provides in clear form the solutions to any variable-voltage angular-position servomechanism with two time delays for either simple error control or error plus error rate (anticipatory) control. The solutions include system frequencies and per cent damping per cycle that are applicable to any system disturbance, and maximum overshoot data are provided for the case of suddenly applied constant velocity. A typical practical example of the use of the data is given.

It should be emphasized that the solutions are directly applicable only to systems that are approximately linear, although the correct order of magnitude of results will be obtained even for systems that materially depart from linearity.

Appendix

Equations for Figure 1

t_a = armature time constant
t_f = field time constant
T_a = anticipation time constant
K = stiffness constant

Equation for armature circuit:

$$E_g = R_a i + L_a pi + gp\theta_0; \quad p = \frac{d}{dt}$$

Equation for motor torque:

$$bi = Ip^2\theta_0$$

Giving the mechanical torque equation

$$M_a = \frac{bEg}{R_a} = \frac{L_a I}{R_a} p^3\theta_0 + Ip^2\theta_0 + \frac{bg}{R_a} p\theta_0$$

$$M_a = (1+t_a p)Ip^2\theta_0 + cp\theta_0$$

Controller torque M_c for simple error control:

$$M_c = \frac{K(\theta_i - \theta_0)}{(1+t_f p)}$$

Controller torque for error control plus anticipation:

$$M_c = \frac{K(1+T_a p)(\theta_i - \theta_0)}{(1+t_f p)}$$

Dimensionless parameters for generalized analysis:

$\omega_n = \sqrt{K/I}$ = undamped natural frequency with no time delays

$r = \frac{c}{2\sqrt{IK}}$ = ratio of actual to critical damping with no time delays

Dimensionless time constants = $\omega_n t$
Dimensionless system frequencies = ω/ω_n
ω_1 = suddenly applied constant velocity

$\theta_{ss} = \frac{2r\omega_1}{\omega_n}$ = steady-state error for suddenly applied constant velocity

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Circuit Cushioning of Gas-Filled Grid-Controlled Rectifiers

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Synopsis: In certain common rectifier and inverter circuits, gas-filled rectifier tubes supplying highly inductive loads with firing delayed by grid control, are subjected to the application of high rates of rise of initial inverse voltage. This phenomenon results in short tube life because of the sputtering of anode material by the impact of residual ions attracted at high velocity to the negatively charged anode with consequent gas cleanup. The paper describes a method of slowing down or cushioning this rate of rise of initial inverse voltage. A small resistance and capacitance circuit connected between cathode and anode of each tube delays the voltage rise the few microseconds necessary to eliminate gas cleanup. Life test data and practical applications are cited.

GAS CLEANUP, or gradual disappearance of the gas filling of gaseous discharge tubes was noted by Plucker in 1858, and later studied more extensively.[1] The present work was undertaken to explore the phenomenon as related to hot-cathode xenon- and argon-filled grid-controlled rectifiers.

The exploration was prompted by a reported tube life of 40,000 hours without cleanup in one circuit, contrasted with a circuit which consistently caused cleanup within 250 hours.

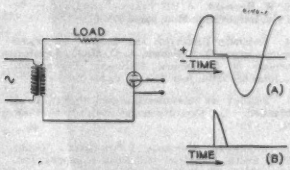

Figure 1. Circuit of test 1 with oscillograms of tube voltage and current

A—Voltage across tube
B—Current through tube

Cleanup Test Data

Life tests were initiated in 1936 under the tube operating conditions listed in Table I, using a tube type which tests on resistive load under widely varied conditions had shown to be free from gas cleanup and dependable for lives in excess of 3,000 hours.

Before this work was undertaken, it was thought that cleanup might accompany rapid ionization.

Test 1 was designed to give rapid current buildup by reason of a low impedance power supply and transformer. Tube current rose abruptly from zero to 90 amperes each cycle. As the test was at overload, the life obtained was considered normal. Tests after failure showed that cleanup did not occur. Hence rapid buildup of ionization is not cause for cleanup at least up to rates of current rise of several million amperes per second.

Test 2 applied high initial inverse voltage caused by the current carry-over forced by the inductive load, shown in the diagrammatic oscillograms of tube voltage and current in Figure 2. Here no rapid buildup of ionization occurred, but in each cycle, at the end of conduction, a high inverse voltage abruptly appeared. This initial inverse voltage is indicated on the oscillogram of the tube voltage in Figure 2. With this circuit condition rapid cleanup occurred.

In test 3 the load inductance was made larger to prohibit appreciable change of current throughout the cycle. At the end of each cycle, the inductance generated the instantaneous voltage necessary to overcome negative supply voltage, thus forcing current to flow through the conducting tube until relieved by the firing of its successor. Current flowed through each tube in square blocks, thereby maintaining full current just prior to applying the initial inverse voltage. This test caused drastic cleanup.

Table I further indicates by test 4 that lowered initial inverse voltage alleviates cleanup somewhat, whereas increased frequency in test 5 aggravated cleanup.

As a result of this and other data, and numerous installations where it was shown by test that cleanup did not occur, it was concluded that gas cleanup would not occur, provided:

1. The circuit did not apply each cycle high initial inverse voltage immediately following substantial current conduction.
2. No sizable ion current was drawn to the grid during tube conduction nor was a sizable electron current drawn to the grid during periods of high inverse voltage on the anode.
3. There were no parasitic glow discharges or tube abnormalities.

Items 2 and 3 had been found some years previously to be possible causes for cleanup. In the tests reported in Table I, suitable grid resistors were used (approximately 50,000 ohms) to eliminate cause 2. Many previous tests of this tube type on resistance loads under various conditions had demonstrated that the tubes were free of cleanup from cause 3.

Since 1937, limitation 1, as part of the tube application notes of one company, prohibited many commercial applications of gas-filled tubes. Desiring to remove this restriction, the details of the abrupt transfer from conducting current to withstanding inverse voltage were probed further.

Commutation

This transition for the circuit shown in Figure 3 is depicted with expanded time scale in Figure 4. The process of current commutation commences at instant t_4 as the tube about to enter construction 2 is fired by grid action. Its anode voltage falls precipitously and conduction current arises. However, leaving tube 1 continues conduction by reason of the inductance of the supply and transformer, shown schematically as equivalent leakage inductances L_1. Similar inductance L_4 momentarily limits the growth of current through entering tube 2. With both tubes conducting concurrently, both anodes are at the same potential and

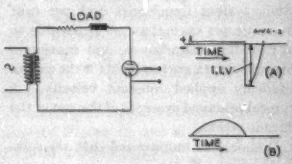

Figure 2. Circuit of test 2 with oscillograms of tube voltage and current

A—Voltage across tube
B—Current through tube

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the transformer is temporarily short-circuited. Full voltage during this period is applied to L_1 and L_2 in a direction to increase current in L_2 and depress it in L_1. By the time t_1, current through leaving tube 1 has been brought to zero and load current transferred to entering tube 2. Rectifier action prohibits reverse current, therefore the rate of change of current through L_1 disappears and the voltage across it collapses from maximum value to zero. This applies the full negative voltage of the winding to the leaving anode. Simultaneously, load current, which cannot change rapidly because of the high load inductance, becomes the only current flowing through

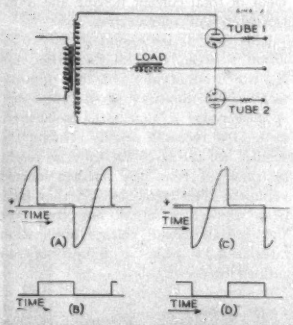


Figure 3. Circuit of tests 3, 4, 5, and 6 with oscillograms of tube voltages and currents

A—Voltage across tube 1
B—Current through tube 1
C—Voltage across tube 2
D—Current through tube 2

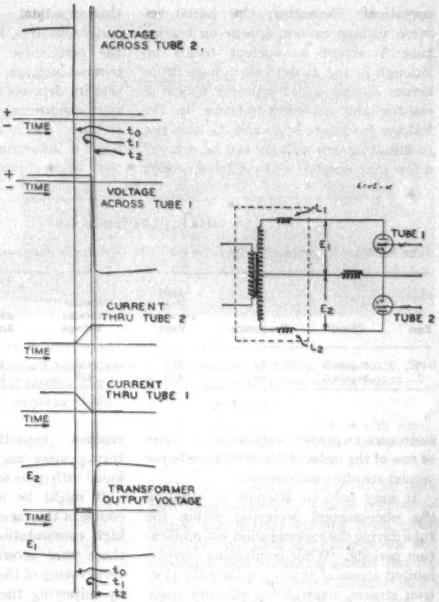
L_2, causing voltage across L_2 to disappear and further increasing the initial inverse voltage on leaving tube 1. Stray capacitances and core losses in the various inductances prevent the initial inverse voltage from appearing absolutely instantly. It is not until t_2, that full initial inverse voltage appears. However, on circuits of a few kilowatt capacity, voltage often appears at a rate of over 100,000,000 volts per second. All of the commutation events just described occur in a time so small compared to 60-cycle waves that they often go unnoticed.

Cushion Test Data

Experiments were conducted in which the rate of rise of the initial inverse voltage was modified by adding a capacitor and resistor across each tube, as shown in Figure 5. The capacitor-resistor cir-

Figure 4. Details of commutation in circuit shown in Figure 3

Showing equivalent circuit and oscillograms of tube voltages, tube currents, and transformer output voltages during current commutation and rise of initial inverse voltage



cuits have been called cushion circuits to indicate that they cushion the fall of anode potential.

Life tests using tubes of lower current rating than those reported in Table I were run under the conditions listed in Table II.

Cleanup occurred in all tubes tested in test 6, whereas none was detectable in any tube after failure in test 7. As before, the particular tube type had been thoroughly tested on various resistive loads and found to be free from cleanup. In addition to demonstrating the effectiveness of cushioning, this test gave further evidence that initial inverse rather than build-up of ionization was responsible for cleanup, as test 7 built up conduction current slightly faster than test 6.

Operation of Cushion

The operation of the cushioned circuit of Figure 5 may be described as follows. For the half cycle prior to entry of tube 2, cushion capacitor C_1 is discharging through R_1 and tube 1. It stands discharged at the moment t_0 when entering tube 2 fires. Current commutation is instituted at t_0 as previously described. Also, entering cushion capacitor C_2 is discharged through R_2 and tube 2. Time t_1 marks the end of current com-

Table I. Life Test on Tube

Tube Rating: 750 Applied Peak Forward Volts, 5 Amperes Average Current, 60 Amperes Peak Current

Test	Circuit	Frequency	Applied Peak Forward Voltage	Applied Peak Inverse Voltage	Initial Inverse Voltage	Avg Amp	Peak Amp	Hours Life
1	Figure 1	60	155	155	0	10	90	1,955
2	Figure 2	60	15	650	650	5	14	269
3	Figure 3	60	650	650	650	5	10	25
4	Figure 3	60	310	310	310	4	8	120
5	Figure 3	500	680	680	680	5	10	3

mutation. Thereafter, the initial inverse voltage cannot appear on leaving tube 1 except as current builds up through L_1 and L_2 to cause voltage drops across R_1 and C_1. By proper choice of resistor and capacitor relative to the leakage inductances L_1 and L_4, this rise of initial inverse voltage can be delayed a few microseconds and yet have enough resistance to prevent oscillations. Rates of rise of the order of 10,000,000 volts per second are often satisfactory.

It may help to attempt to visualize the phenomenon occurring within the tube during the commutation and application periods. While conducting current, ionized atoms of xenon populate the electron stream, neutralizing electron space charge. The number of ions varies as some function of current. On a decrease of current, the ion requirements will decrease, allowing the excess to seek electrons and return to atoms. A short time, that is, the order of ten^{-4} seconds, is required for the ionization to readjust to the new conditions. Thus, at the instant that current reaches zero, there still will be present residual ionization representing current flow some microseconds earlier.

At the cessation of current, the initial inverse voltage appears on the anode at the rate established by the circuit. The negative anode attracts residual positively charged ions to it. If ions, being relatively heavy particles, fall through a high potential drop, they acquire enough momentum to sputter or evaporate anode material when they impinge.[3] Sputtering appears to trap gas atoms both in the anode and in the deposited film of sputtered material. If negative voltage is applied slowly enough to allow sweeping out the residual ions at relatively low voltage, sputtering is avoided and cleanup eliminated.

To expedite testing, sensitive pressure gauges were attached to tubes which were then operated under varying current commutation rates and initial inverse voltage application rates. Cleanup could be detected in shorter testing time by this expedient. These data are necessarily tentative, but they do disclose that the permissible rate of rise of initial inverse voltage, above which cleanup sets in, depends upon current commutation conditions. Low reactance transformers, which commutate swiftly, require a lower rate of application of initial inverse voltage, that is, larger cushion capacitors. High reactance transformers may be completely cushioned with quite small capacitances.

It might be noted that, during the course of the experiments using extremely high commutation and recovery rates, there were several cases where the inverse rating of the tube could be changed by adjusting the recovery rates. This undoubtedly has a bearing on the problem of arc-backs, particularly in view of the reported fact that many arc-backs in mercury-arc rectifiers occur just after current commutation.[3,4] This seems to merit a separate inquiry and report.

Based on the pressure gauge tests, the safe rating for the maximum rate of rise of initial inverse voltage is being specified for the present on some tubes as

$$\frac{K}{A_{10}} = \text{maximum safe rate of rise of intial inverse voltage in millions of volts per second}$$

where

K is a constant for each tube type (6.6 for a typical 6.4 A tube)

A_{10} is the current flowing 10 microseconds before current zero

A_{10} can be determined from measurement of total current flowing and duration of current commutation.

This formulation assumes a linear relation between residual ionization and A_{10} which admittedly is a first approximation, but appears to cover the range of measurable voltage rates moderately well. The factor K usually is larger the smaller the rating of the tube, as might be expected from the smaller ionized volumes. This, plus the fact that fractional ampere circuits do not often have high initial inverse voltage application rates, usually makes it unnecessary to cushion low power tubes.

Table II. Life Test on Tube

Tube Rating: 450 Applied Peak Forward Volts, 1 Ampere Average, 8 Amperes Peak Current

Test	Circuit	Frequency	Applied Peak Forward Volts	Initial Inverse Voltage	Avg Amp	Peak Amp	Hours Life
6	Figure 3	60	423	423	1	2	449
7	Figure 5	60	423	423	1	2	14,200

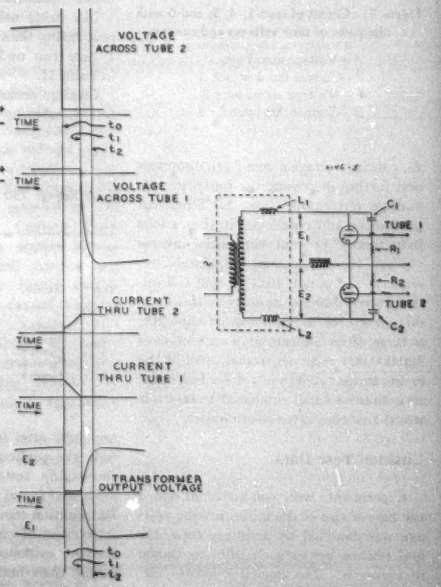


Figure 5. Details of commutation of cushioned circuit

Showing equivalent circuit and oscillograms of tube voltages, tube currents, and transformer output voltages

There is a small power loss in the cushion resistors. It is usually less than two per cent of full output and may be made considerably smaller by proper transformer design.

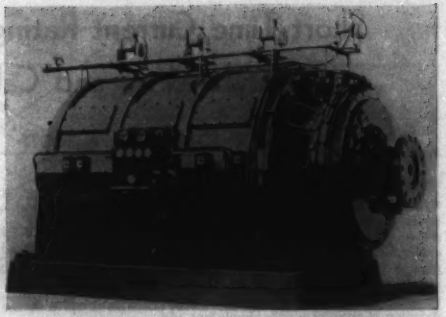


Figure 6 (right). A 12,000 horsepower speed-controlling magnetic clutch regulated by cushioned rectifier

Measurement

Commutation and cushioning occur so rapidly that they ordinarily escape detection. However, by proper cathode-ray oscilloscope technique they may be observed and measured readily. Anode-to-anode voltage properly attenuated is applied directly to the oscilloscope deflection plates. This voltage wave is viewed with an expanded sweep voltage that is a multiple of supply frequency. It is convenient to apply a synchronizing signal from a small capacitance connected to an anode. The scene thus obtained permits the time of current commutation and the rate of rise of the initial reverse voltage to be scaled off.

Figure 7 (left). Control rectifier unit for magnetic clutch

There are two sources of error that deserve mention. The signal attenuator must be noninductive and without capacitance errors. The stray capacitance within the oscilloscope between its power source and the oscilloscope ground lead must not be allowed to distort the reading.

Application

The following circuits apply initial inverse voltage if firing is throttled by grid action.

Cushioning is indicated to accommodate the maximum amount of throttling expected in service.

1. Full wave or polyphase rectifiers with inductive load.
2. Polyphase rectifiers with any load operating in continuous current region.
3. Parallel inverters.
4. Half wave control rectifiers with inductive load and back rectifier (only back rectifier requires cushioning).

The conclusions arrived at by life tests have been verified by a large number of actual installations ranging from small controlled rectifiers supplying motor and generator field excitation all the way up to the 12,000-horsepower adjustable speed magnetic clutch shown in Figure 6. Magnetizing power for such units is controlled precisely by a cushioned rectifier as shown in Figure 7. Cushioned control rectifiers have been used successfully over the past two years in many such applications which formerly were impractical.

Conclusions

Experiment indicates that there is a safe rate of rise of initial inverse voltage on gas-filled grid-controlled rectifiers above which gas cleanup may be expected and below which cleanup may be completely avoided.

Tests indicate that the safe rate of rise of initial inverse voltage is a function of the current commutation and of tube construction. This rate of rise may be controlled by proper cushion circuit design.

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Short-Time Current Ratings for Aircraft Wire and Cable

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Synopsis: This paper gives the results of a series of tests on two sizes (AN-16 and AN-8) of insulated aircraft wires and cables, which were made to determine their permissible short-time current-carrying capacities. The times under consideration ranged from 0.01 to 1,000 seconds. A description is given of a very simple but adequate electrical test together with an accompanying insulation test to determine what are considered permissible transient temperatures. Tentative recommendations of short-time current-carrying capacity for aircraft cable sizes AN-22 to AN-00 are made.

WIRE SIZES for aircraft power supply and control circuits, selected on the basis of steady-state temperature rise may prove inadequate for other conditions of operation. Short circuits arising from gunfire or other causes must be anticipated and protected. A great many motors are used to drive the many devices and controls found on the modern plane.

If small wire sizes such as numbers 22 to 6 are used for supplying power to induction motors, d-c motors, and similar loads which may take six times rated current or more during the starting period, and if this branch line is protected by means of temperature overload relays, these branch lines should be capable of carrying six times motor current without exceeding a permissible temperature for a duration corresponding to the time required for the overload relay to trip. It has been recognized commonly that these smaller wire sizes generally will be deficient in their ability to carry this overload for the required period when the selection of the wire size is based entirely on its continuous rating. This deficiency generally is not present in the larger wire sizes.

The purpose of this paper is to supply needed data on aircraft wires to application engineers who sometimes have made the error of using too small a wire size on loads of this character because adequate information generally has not been available. It should also be pointed out that although these data were taken on wires which had insulation appropriate for 30-volt d-c aircraft application, some spot checks were made on a few sizes of wires insulated for 600-volt service and it was found that their short time ratings were quite close to those of the aircraft wires. The insulation on the aircraft wire is actually comparable to that on the 600-volt wire in spite of the lower voltage of the aircraft service. It is believed permissible to apply the present data on aircraft to industrial 600-volt insulated wires, or similar, until data are made available for each specific type of wire. Any difference that may be found between these two types of wires will be on the safe side.

Transient currents in excess of the normal continuous current ratings of the supply wiring and cabling of military aircraft electrical systems are caused by:

1. Starting currents of connected electrical devices when starting under normal conditions.

2. Starting currents of connected electrical devices during abnormal conditions, such as after a period of low temperature shut down during which bearing lubricating oils and greases have congealed or during which connected moving parts have iced or frozen.

3. Actual short circuits resulting from faulted conductors caused by sustained abrasion, vibration, or gunfire.

Circuit breakers or contactors controlled by temperature overload relays are the commonly used means to limit the duration of these currents to prevent the wire temperature from rising to values which would result in damage to the insulating covering of the wires.

The safe time duration depends on the following factors in addition to the current:

1. Initial wire temperature.

2. The heat storage capacity of the copper conductor itself.

3. The heat storage capacity of the wire insulation and its relation to that of the copper conductor.

4. The radiation characteristics of the wire covering.

5. The external air temperature, pressure, and the degree of cooling provided by convection and ventilating air currents.

6. The groupings of the wires in bundles or runs.

The steady-state continuous rating of the wire based on 100 degrees centigrade maximum insulation temperature is governed by radiation characteristics and external cooling factors. These are well established for sea-level conditions in still air, but further work is necessary to study altitude conditions and the special ventilation conditions that exist in a plane in flight. They will not be discussed further in this paper.

The short-circuit momentary-overload condition involves so short a time interval that its safe time duration is governed largely by the initial temperature of the wire and its heat storage capacity at the temperature which may be determined as safe for that time exposure. Values of safe times can be calculated. This paper will discuss these limitations only briefly. For the present, it is assumed that the maximum safe instantaneous copper temperature for all wire sizes is 150 degrees centigrade, for time intervals below one second. Fuse and circuit-breaker designers for many years have used so-called I^2t curves in providing overload protection to circuits. These curves are calculated on the assumption that all the energy is absorbed in heating the copper conductor. They include curves of temperature rise for various currents and times. Such a set of curves is shown on Figure 3. These curves are very satisfactory for periods of time below one second, which include most true short-circuit occurrences.

The problem, then, of selecting wire sizes resolves itself into

1. The selection of wire size for steady-state conditions generally is made on the basis of the continuous rated current capacity of the wire. These ratings are based on rules well established in the industry, though for aircraft use they are based on 100 degrees centigrade maximum operating temperature (70 degrees centigrade rise over 30 degrees centigrade ambient temperature) rather than more usual conservative values.

2. The selection of wire size for overloads of known or estimable duration below one second can be made on the basis of the previously mentioned I^2t curves. It is recommended that 150 degrees centigrade be the maximum allowable temperature to be attained by the copper.

It is recommended that the selection of wire sizes for overloads whose duration is between 1 second and 100 seconds be made on the basis of curves presented in this paper. These curves are given in Figure 4, and are derived from the present series

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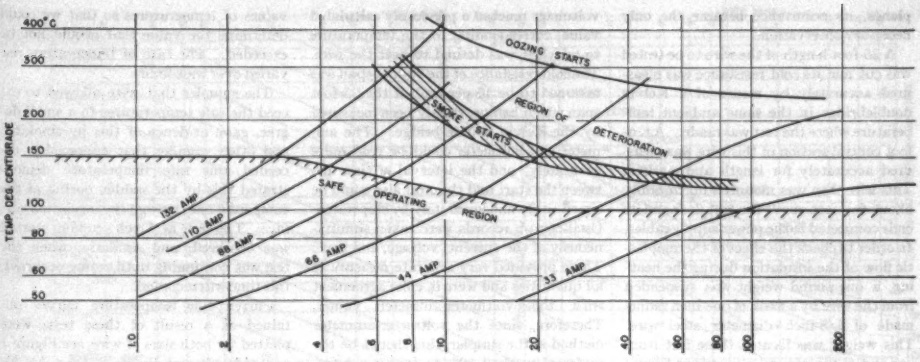


Figure 1. Current-time-temperature curves from 30 degrees centigrade ambient temperature for aircraft cable size AN-16

of tests conducted to study the damaging effects on the insulation of overload currents whose duration was between 0.1 second and several hundred seconds. The tests and the derivation of the curves are described in the following paragraphs.

Method of Test

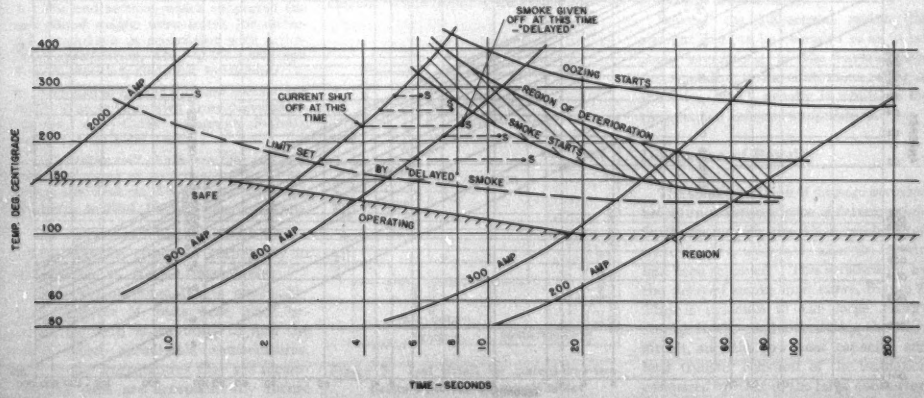
There is no accepted standard method for determining the short-time current-rating of wires. Some engineers have measured temperature rise of wires by means of thermocouples embedded in the center of a wire or brazed to the copper strands. Others have used an oscillograph to obtain a simultaneous reading of current and voltage, while others have used the voltmeter-ammeter method. In this investigation the authors used all three methods and compared their results. Based on this work we will recommend a method which we found was the most practical and yet gave a sufficiently accurate result.

There are two important factors that must be accurately determined when making a test of this kind to ascertain the permissible short-time current-carrying capacities of various wire sizes.

The first is to be sure that the recorded temperatures are accurate, so that the insulation is actually subjected to contact with a wire of the recorded temperature. To illustrate, it was found that the thermocouples gave readings very appreciably lower than the actual wire temperatures as determined by resistance methods. Thermocouples are not suitable for determining temperatures of rapidly heated wires (there are also other limitations for the use of thermocouples).

The second factor is to judge correctly the degree of damage to the insulation that resulted from the above temperature and times. There are standardized methods for measuring the dielectric breakdown and also the cold bend test, but with these having been made there still remains a fair degree of judgment that must be used which should be seasoned with a fair degree of background on this subject. Figures 6A, B, and C, show what is to be expected of such tests. However, as it was found actually that the evolution of smoke was observed even before actual deterioration occurred, and since smoking cannot be tolerated in air-

Figure 2. Current-time-temperature curves from 30 degrees centigrade ambient temperature for aircraft cables size AN-8



planes, its occurrence became the only necessary observation.

A 25-foot length of the wire to be tested was cut and its cold resistance was measured accurately by means of a Kelvin doublebridge in the same ambient temperature where the test was made. A ten-foot central section of this wire was measured accurately for length and marked. This wire then was mounted horizontally about five feet above the test floor and its ends connected to the power supply cables. In order to check the effect of thermoplastic flow of the insulation during the heating, a one-pound weight was suspended from the wire by a hook of one-inch radius made of 1/8-inch diameter steel wire. This weight was located three feet from one end of the wire as indicated in Figure 5. Two steel needles were forced through the insulation and the stranded wire at the two points which marked the ten-foot length. To each of these steel needles was soldered a six-inch length of ten-mil diameter nichrome wire, and this in turn, was soldered to the necessary length of copper wire which ran to the voltmeter terminal. The purpose of the nichrome wire was to minimize the amount of heat that was conducted from the test wire into the voltmeter leads. The circuit arrangement was that shown in Figure 5.

A field controlled d-c generator was the source of power. Current was applied by closing a contactor at the zero time and held constant until the voltage on the voltmeter reached a previously calculated value, corresponding to the temperature to which it was desired to heat the wire. The cold resistance of the 10-foot span was assumed to be 40 per cent of the 25-foot span which had previously been measured by the Kelvin double bridge. The ammeter and voltmeter could be read quite accurately, and the interval of time between the start and the stop also could be timed easily and accurately by stopwatch. Oscillograph records were taken simultaneously of the current, voltage, and time. These provided very accurate measure of all quantities and were in close agreement with the voltmeter-ammeter values. Therefore, since the voltmeter-ammeter method is the simpler, this should be the preferred method, except for time intervals below five seconds where the oscillograph must be used.

Samples of aircraft cable sizes AN-16 and AN-8 were subjected to a number of current values, and at each of these different values of current, wires were allowed to rise to several predetermined values of temperatures so that we could determine the value that should not be exceeded. The rate of temperature rise varied over wide limits.

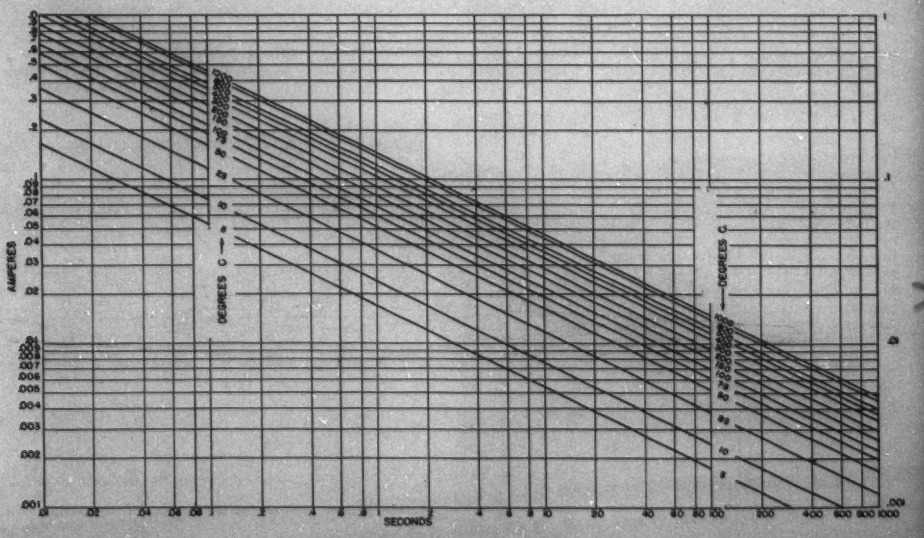
The samples that were allowed to exceed the safe temperatures to a small degree, gave evidence of this by smoking, and other samples that appreciably exceeded this safe temperature demonstrated this by the sudden oozing of the compound out through the insulation surface. The time at which smoking started was observed, and similarly, when the test was continuing until oozing occurred, this time was recorded.

Current-time-temperature curves obtained as a result of these tests were plotted for both sizes of wire, see Figure 1 (size AN-16) and Figure 2 (size AN-8). These curves show temperatures plotted against time for all of the current values tested. The times at which smoke occurred for each current value are shown by the shaded area. The time at which oozing occurred is shown by the wave labeled oozing starts. In the case of the larger wire AN-8, it was observed during the tests that smoking for some values of current occurred after the current had been shut off. This is due to the great relative heat storage capacity in the larger conductor compared to that of its insulation. The smaller wire gives up its heat to its insulation with a rapid drop in temperature. This delayed smoke is shown on Figure 2 and indicated by the notes calling

Figure 3. Time–current curves of one circular mil of annealed copper

Calculated on these assumptions:

1. Radiation neglected
2. Resistance of one centimeter cube of copper at 0 degrees centigrade = 1.589 microhms
3. Temperature coefficient of copper at 0 degrees centigrade = 1/234



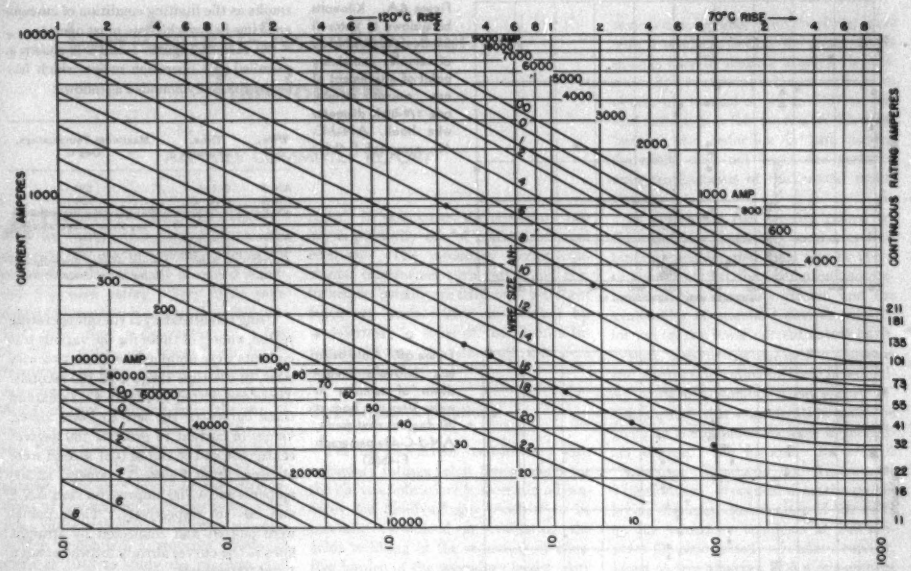


Figure 4. Suggested current-time ratings for aircraft cable AN-J-C-48a for 30 degrees centigrade ambient temperature

attention to this phenomenon. The safe operating region shown on Figures 1 and 2 is drawn at what is considered a sufficiently safe margin below the temperature time limitations imposed by smoke to represent safe operation.

After the test exposure described earlier, each sample of wire was tested for insulation condition as follows:

1. The end sections which supported the one pound weight were tested for dielectric breakdown in accordance with Army-Navy specification, AN-J-C-48a paragraph F-4b(5), entitled, Dielectric Breakdown.
2. One half of the ten foot test section was tested in accordance with Army-Navy specification, AN-J-C-48a paragraph F-4b(6), entitled, Cold Bend Test.
3. The other half of the ten foot test section was tested in accordance with Army-Navy specification, AN-J-C-48a paragraph F-4b(4)c, entitled, Water Immersion Test.

The results of these dielectric breakdown tests are presented graphically in Figures 6A, B, and C, respectively.

It should be noted that a reasonably large number of tests were made because we were endeavoring to find the short time permissible temperatures. But if the temperatures that are recommended here are accepted, any future tests can be simplified very greatly by merely finding the time required for any selected current to produce the maximum temperature shown in Figures 1 and 2.

Recommended Test Procedure

Establish by trial a current which will produce the allowable temperature rise (usually 70 degrees centigrade) in approximately 20 seconds (between 10 and 40 seconds) and determine by test the exact time required. On a sheet similar to Figure 4, locate this one point of time and current. Then from Figure 3 calculate the current required to heat (on a no-loss basis) the wire size in question to a value equal to 150 degrees centigrade minus the assumed ambient temperature in 0.01 second. This will give another point on the afore-mentioned sheet. Then draw a straight line between these two points and that will be the permissible short-time current-carrying ability of that wire size. By testing in this simple manner about four or five sizes of wire, for any one type of wire the whole range of ratings can be drawn in by proportioning the intermediate sizes in proportion to their respective cross sections.

Beyond the 100-second region this straight line can be extended so as to become asymptotic to the current line, corresponding to the continuous rating of this wire, which usually is available for the assumed ambient temperature.

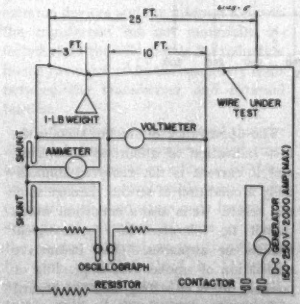


Figure 5. Test circuit for current-time-temperature rise test on aircraft cables

Discussion of Results

The smoke criterion of damage occurred before any other evidence of deterioration. On the larger wire, size AN-8, smoke often was delayed considerably after the current had been removed. This is indicated by the delayed smoke limit curve, Figure 2. This is evidence of the large energy storage in the conductor during the short circuit, and the low heat capacity and heat transfer constant of the insulation compared to that of the large conductor.

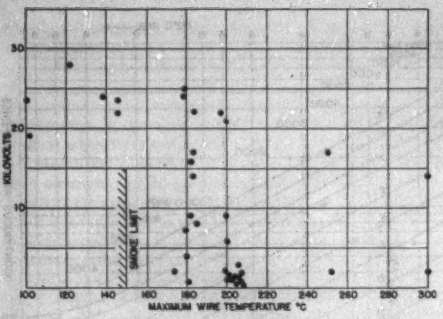


Figure 6A. Kilovolts breakdown in water at 25 degrees centigrade of samples containing point of attachment of one pound weight, one 1/8-inch diameter wire hook, AN-J-C-48a paragraph F-4b(5)

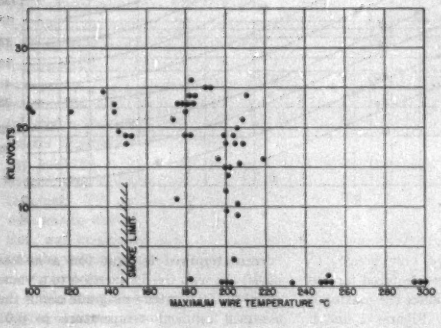


Figure 6B. Cold bend test kilovolts breakdown of samples in water after one hour at 40 degrees centigrade, AN-J-C-48a paragraph F-4b(6)

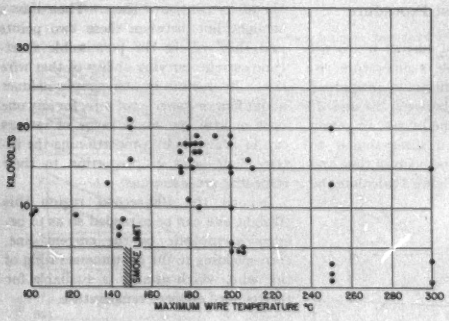


Figure 6C. Kilovolts breakdown in water at 50 degrees centigrade after immersion in water for 20 hours at 50 degrees centigrade AN-J-C-48a paragraph F-4b(4)c

The dielectric breakdown values given in Figures 6A, B, and C, gave evidence of deterioration only when the insulation had been carried to a considerably higher temperature than that at which smoke first appeared. Dielectric breakdown results vary over a large range, but do indicate definite deterioration when the wire has been exposed to temperatures of 200 degrees centigrade for the short time intervals covered by these tests.

The appearance of smoke, then, is the first indication of abnormal conditions, and if current is not removed immediately a condition of serious damage soon will result. It is also a condition which cannot be tolerated for psychological reasons in airplanes. The instinctive association of smoke with impending or possible fire is so strong, and the hazard of fire so great in an airplane, that we have adopted the slightest appearance of smoke as the limiting condition of current and time below which we must operate.

On each of Figures 1 and 2 is shown a so-called safe operation region which has been arbitrarily bounded as follows:

Wire, Size	Time, Seconds	Maximum Temperature, Deg C
AN-8	0–1.5	150
AN-8	Over 20	100
AN-8	1.5–20	From sloping line connecting these temperatures
AN-16	0–2.5	150
AN-16	Over 20	100
AN-16	2.5–20	From sloping line connecting these temperatures

Using this boundary of the safe operating region, values of times for the various test currents were obtained for these two wire sizes, in the time range 1 to 100 seconds. These are plotted on Figure 4. To extend these curves to the left to lower times, values of current to produce 150 degrees centigrade at the end of 0.01 second were obtained from Figure 3, namely, 12,300 amperes and 1,700 amperes for sizes AN-8 and AN-16, respectively. These points were plotted and connected by straight lines to the curves already drawn between 1 and 100 seconds.

To extend the curves to the right for times greater than 100 seconds, the curves were connected by smooth arcs to the steady-state values, 73 amperes and 22 amperes, respectively, which were obtained from the steady-state ratings given by the AIEE committee on aircraft wire and cable.

Curves for other wire sizes between 16 and 8 were interpolated on the basis of the theoretical spacing. Similar extrapolation was made to wire sizes 20 and 00. These curves are tentative only and subject to verification by further tests.

Conclusion and Recommendations

Current-time-temperature tests on wires, carried to the point at which smoke first appears, provide a suitable method of determining the short-time current-carrying characteristics of wires. The temperature-time measurements must be made carefully and accurately. Wire temperature should be determined by copper resistance, using a voltmeter-ammeter method for times down to five seconds and using an oscillograph method for shorter times. Thermocouple measurements are not recommended.

The suggested current time ratings for aircraft cable AN-J-C-48a presented in Figure 4 based on a 30 degrees centigrade ambient temperature is recommended for consideration.

Low-Current-Secondary Current Transformers

AN AIEE COMMITTEE REPORT

APPLICATION REQUIREMENTS for current transformers sometimes indicate the use of secondary currents lower than the generally accepted standard 5-ampere rating. Very little published information is available on this subject, other than a description of a few specific installations where such transformers have been applied. The natural question arises as to the advantages and disadvantages resulting from the use of current transformers with secondary ratings below five amperes, and under what circumstances their use should be considered. Because many of the applications of low-current secondaries involved relay protection, the AIEE relay subcommittee appointed a working group in October 1943 to study the problem, and from that study, gives recommended practice for their use.

Applications

The principal application of low-current-secondary current transformers is in those installations involving long runs of secondary leads where the resistance of the leads (utilizing normal size copper conductors) becomes very high, thus imposing on the current transformer excessive lead burden in comparison to the useful burden. A brief summary of the problems to be considered for such installations is covered in this paper.

Another application of current transformers using secondary ratings of other than five amperes, occurs in those installations requiring the paralleling of the secondaries of transformers subject to widely different normal primary load currents. In such cases, the secondary rating is primarily one of convenience and economy. The secondary circuit constants, transformer turn ratios and performance, usually are fixed on a 5-ampere secondary basis. This is dictated by transformers in some of the circuits involved having the standard 5-ampere secondary rating.

Comparison of Solutions

The use of current transformers with secondary ratings below five amperes for the above applications has certain advantages and disadvantages which must be carefully considered in evaluating the gains resulting in the reduction of effective burden of the secondary leads. Any general comparison of these advantages and disadvantages should be made on the common basis of equal volt-ampere energy requirements for the relays, instruments, and meters, irrespective of the secondary rating. Changing the current rating of these devices in no way reduces the energy required for their operation. A reduction in energy is just as desirable on the basis of five amperes as on a lower current rating basis, and minimum operating energy is a controlling factor in the design of this type of equipment.

On the basis of constant volt-ampere energy requirements, a reduction in secondary current rating results in a corresponding increase in secondary voltage rating. The energy consumption in the external devices and the internal losses in the transformer are not materially affected, thus, the only gain is the reduction in energy consumed by the secondary leads between the transformer and external burden.

As an example, if it is assumed that the distance between the current transformer and the instruments or relays is 500 feet, and standard control cable such as one consisting of conductors each having 19 strands of number 22 wire is used, the burden imposed on the transformer by each secondary lead is 11 watts at 5 amperes. Under the same conditions, with a one-ampere secondary, the lead burden would be 1/25 or 0.44 watt per lead at rated current. Thus, in some cases, smaller wire could be used with a resulting saving of copper. Such savings may be limited, however, by the necessity of retaining a larger wire size to obtain mechanical strength. Unless the lead burden is a fair portion of the total burden, this reduction in lead burden materially does not lessen the performance requirements of the current transformer.

In evaluating the benefits gained by the reduction in effective secondary lead burden, consideration must also be given to the effects on the insulation requirements of the secondary circuit, and the availability of standard devices suitable for use on the lower current rating basis.

With low-current secondary currents and the corresponding increase in secondary voltage (assuming equal energy requirements), due consideration must be given to the required increase in secondary voltage. For instance, the present "American Standards for Instrument Transformers" recognize a maximum relaying accuracy classification of 800 volts on the secondary terminals at 100 amperes (20 times rated) secondary current, based on five amperes. On a one-ampere basis, the secondary terminal voltage would be 4,000 volts, and the secondary insulation should be well in excess of this value for safe operation. Furthermore, the present open-circuit voltages on switchboard transformers commonly run from 500 to 5,000 volts crest. The logical basis for consideration of a one-ampere-secondary, therefore, is that the open-circuit voltages will be five times as great, or from 2,500 to 25,000 volts crest. It is apparent that the standard one-minute potential test of 2,500 volts to ground for the secondaries of current transformers should be increased to 12,500 volts for one-ampere secondary ratings. Similarly, relays and instruments used with one-ampere secondary transformers should have the one-minute potential test of 1,500 volts to ground increased to 7,500 volts.

The above requirements for insulation are based on general applications. However, for those applications requiring the use of low-current-secondary current transformers to minimize lead burden, and which will be subjected to considerably less than 20 times normal current, a suitable transformer could be made with an insulation level to meet the actual secondary voltage requirements.

While it is quite true that the secondary voltages existing at normal currents are low, the high voltages occurring on high values of overcurrents and on open circuits sometimes are overlooked. In cases

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This report was prepared by a working group of the relay subcommittee, AIEE committee on protective devices, consisting of S. C. LEYLAND (M '43, *sponsor*), manager, relay section, meter engineering department, Westinghouse Electric Corporation, Newark, N. J.; F. C. POAGE (M '38, *former sponsor*), electrical engineer, engineering department, Ebasco Services, Inc., New York, N. Y.; R. E. NEIDIG (A '38), relay engineer, Metropolitan Edison Company, Reading, Pa.; L. F. KENNEDY (M '39), relay application engineer, General Electric Company, Schenectady, N. Y.; E. C. SCHURCH, (M '35), senior engineer, electrical department, United States Bureau of Reclamation, Denver, Colo.

where only meters or instruments are involved, secondary overvoltage protection may be applied without too much complication. This is particularly true where such protective devices can be permitted to short-circuit the transformer on excessive overvoltage. However, overvoltage protective devices which short-circuit the transformer secondary cannot be used where protective relays are involved, because incorrect relay operation would result. For the foregoing reasons, it is sometimes feasible when considering less than 5-ampere secondary ratings to go to a lower secondary current rating when only meters and instruments are used. When protective relays are used, the problem requires considerable more study.

When considering the use of low secondary current ratings, attention must be given to the use of relays having suitable current ratings. The present complete line of relays (some available with low current taps) was developed to cover the requirements of the field on the basis of the standard 5-ampere secondary transformer ratings. Therefore, their equivalent on a 1-ampere basis does not exist. While a limited number of relays have coils suitable for certain low-current rating applications, to obtain a complete line of such devices with suitably co-ordinated taps and insulation levels would require major development.

In the applications where there is a definite need for a lower secondary current resulting from excessive length of secondary leads, it is desirable to retain standard 5-ampere rating relays and instruments. This may be accomplished by using standard 5-ampere rating main transformers, relays, and instruments with auxiliary current transformers at the main current transformers and the switchboard. It also is possible to use main current transformers with low current secondary rating in conjunction with auxiliary transformers at the switchboard only. It must be remembered, however, that auxiliary current transformers introduce additional burden which tends to offset the gain resulting from reduction in secondary lead burden, and at the same time, lower the accuracy of the over-all transformation because of their own errors. The performance characteristics of the auxiliary current transformers must be as good as those required of the main current transformers, and they should be provided with sufficient insulation to protect the instruments and relays from the higher secondary voltages accompanying the lower currents. Where auxiliary transformers are used, the switchboard circuits should be protected from excessive voltage by the use of suitable short-circuiting devices. Proper consideration must be given to the performance of the auxiliary transformers on a d-c transient having a long time-constant. Auxiliary current transformers fulfilling these requirements increase the cost, require installation space, and reduce the net gain.

Conclusions

In view of the many disadvantages of low current secondaries, compared to the advantage of reduced secondary lead burden or saving in copper, they should not be considered except in special cases. These special cases occur where the secondary lead burden is the major portion of the total burden and definitely causes errors that cannot be tolerated. Then the problem should be studied thoroughly in the light of the foregoing factors. The secondary current rating selected and the secondary circuit arrangements used should be determined as best meets the requirements of the individual application.

The working group feels that the problem of low-current-secondary current transformers is so special that no consideration should be given to standardization at this time.

A Unique Engine-Synchronism Indicator for Aircraft

D. B. PEARSON
ASSOCIATE AIEE

RECENT aircraft design has emphasized multiengine airplanes, especially for commercial transports and military types. Two- and 4-engine planes are commonplace and 6-engine craft are proposed for the near future. Engine synchronism indication, usually between a master engine and each of the others, becomes more important as the number of engines on the airplane increases. It is possible to synchronize two engines by ear, but this method becomes exceedingly difficult for aircraft with more than two engines.

The synchronism indicator, or synchroscope, has been developed to obtain a visual indication of the degree of synchronism that exists between the master and each of the other engines. A discussion of the needs for engine synchronism indication and of the means by which it is obtained, will be presented.

Reasons for Synchroscopes

Perfectly synchronized airplane engines are desirable for several reasons. Better flight efficiency[1] is obtained when the engines are running at the same speed. Planes with constant pitch propellers tend to yaw if the engines are not synchronized exactly. If a condition of near-synchronism exists, such as occurs when synchronizing is attempted with the tachometer indicators alone, a vibration of low frequency is produced. This beat frequency is the arithmetical difference between the high frequency vibrations produced by each engine. Its presence causes high stresses[2] to be set up in the airplane structure which can cause severe damage to the airplane. Fatigue and discomfort for the passengers and crew of the aircraft also are caused by the presence of these vibrations. For example the Air Forces have found it very desirable to use synchroscopes on transport planes to avoid these harmful vibrations

Figure 1. Tachometer generator

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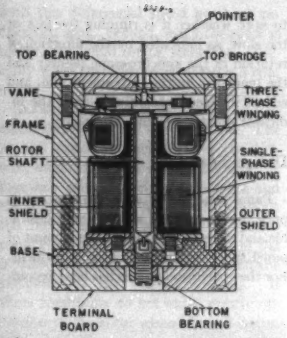


Figure 2. Cross-section view of synchroscope

when carrying sick and wounded personnel.

To promote commercial flying to the greatest degree, passenger comfort is of paramount importance, especially on sleeper-type planes. The synchroscope has been found to be a simple and satisfactory instrument for adjusting engine speeds to obtain efficient flight operation, minimized stresses on the aircraft structure, and to provide a high degree of comfort for the passengers.

Equipment Needed to Indicate Synchronism

No additional source of power or transmitting device is necessary to obtain engine-synchronism indication. Electric tachometer generators[3,4] already installed to operate the tachometer indicators will supply sufficient additional power to operate the synchroscopes. The only additional weight necessary is that of the indicators themselves and the connecting leads.

The most satisfactory tachometer generator has an a-c output with a frequency proportional to engine speed. A typical generator of this kind is illustrated in Figure 1. It is customary to use a reduction gear with a ratio of two to one to drive the generator. Its 4-pole rotor is made of a permanent magnet material such as alnico II. This magnet, as it rotates, induces in the 3-phase winding on the generator stator, a 3-phase a-c voltage having a frequency proportional to the engine speed.

To obtain an indication of the degree of synchronism between two engines, a measurement is made of the frequency difference between the outputs of the generators connected to each engine. To perform this function, the synchroscope uses two stator windings and a rotor. Figure 2 illustrates the mechanical construction of the instrument, while Figure 3 shows the electric circuit. One coil is a 3-phase winding, placed in the form of a toroid on a circular core of high permeability material, such as mu-metal. This winding usually is connected to the generator on the reference, or master engine, which is customarily the one at the extreme left.

Below the 3-phase coil is a single-phase circular stator coil, wound with its axis at

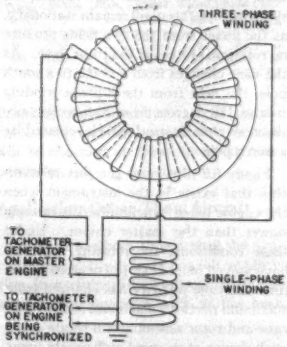

THREE-PHASE WINDING
TO TACHOMETER GENERATOR ON MASTER ENGINE
TO TACHOMETER GENERATOR ON ENGINE BEING SYNCHRONIZED
SINGLE-PHASE WINDING

Figure 3. Electric circuit diagram of synchroscope

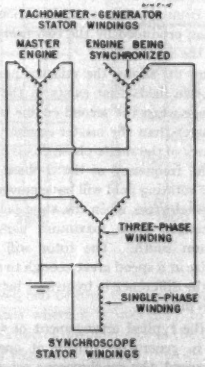


Figure 4. Wiring diagram for synchroscope and tachometer generators

right angles to the plane of the 3-phase winding. This coil is connected to one of the phases of the tachometer generator driven by the engine whose speed is being compared to the master engine.

A rotatable shaft and vane assembly of high permeability material, and supported by suitable bearings, is placed in the instrument so that it can be acted upon by the magnetic fields produced by the two stator windings. A pointer on the shaft gives visual indication of the condition of synchronism that exists between the two engines in question. This construction, embodying two stator coils and a soft-iron rotor, is similar somewhat to that used in switchboard type synchroscopes.[5]

Principle of Operation

When the master engine is running with the synchronism indicator connected as in Figure 4, a rotating magnetic field is produced by the 3-phase winding. This field rotates at the same speed as the engine because the 4-pole tachometer-generator rotor is driven at one-half engine speed. When the engine connected to the single-phase coil is running, there is produced in this winding a magnetic field that alternates at a rate equal to the speed of the connected engine.

As shown in Figure 5, the flux from the single-phase winding crosses the air gap to the shaft and then travels to the vane. After leaving the vane, it passes through the 3-phase core and links with the field from the 3-phase winding. The flux then flows through a washer and a shield of high-permeability material to a second washer at the bottom of the single-phase coil. From the bottom washer the single-phase flux passes to the inner shield, or sleeve, which surrounds the shaft, and then crosses the air gap to the shaft, completing the circuit. All air gaps in this circuit are kept as short as possible to hold the reluctance to a minimum.

When the single-phase winding is energized, its flux, alternating at a frequency proportional to the speed of the engine to

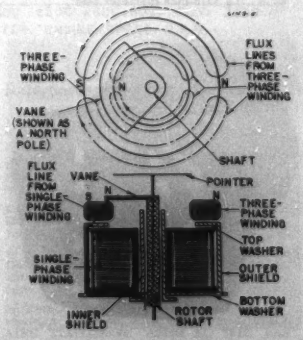


Figure 5. Magnetic circuit diagram of synchroscope

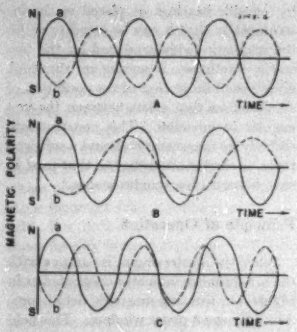


Figure 6. Flux relationships in synchroscope

A—Engines synchronized
B—Second engine running slower than master engine
C—Second engine running faster than master engine
a—Magnetic polarity of a point on the upper surface of the 3-phase winding
b—Magnetic polarity of the rotor vane

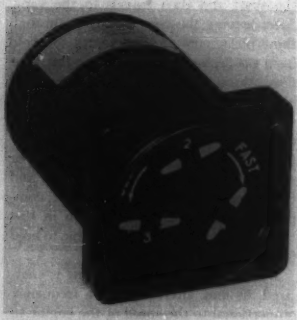


Figure 7. Three synchroscope mechanisms in a 17/8-inch diameter case

Figure 8. Five synchroscope mechanisms in a 23/4-inch diameter case

which it is connected, causes the magnetic polarity of the rotor vane to reverse at the same rate. With the field of the 3-phase winding rotating at a rate proportional to the master engine speed, the rotor assumes a position such that when the vane is a north pole, a south pole from the 3-phase field is at the same point. Figure 6*A* shows the flux relationship in the synchroscope when synchronism exists between the two engines. If the flux in the shaft-and-vane assembly alternates at the same rate as the 3-phase field rotates, the synchroscope rotor will remain stationary, as the fluxes from the two fields produce no rotational forces in the rotor vane. As the vane changes from a north to a south pole, the field from the 3-phase winding rotates 180 degrees from its previous position, so that its south pole is replaced by a north pole.

Figure 6*B* illustrates the flux relationship that exists in the instrument when the engine being synchronized is running slower than the master engine. Under these conditions, the rotating field will have moved more than 180 degrees by the time the vane polarity has changed from maximum north to maximum south. The vane-and-rotor assembly will rotate counterclockwise at a speed sufficiently great to make up the difference in frequency between the two fluxes. This enables the two fields to remain locked together. The torque which causes the rotation is obtained from the forces of attraction and repulsion produced by the two fields acting on the rotor vane.

Figure 6*C* shows the relative position of the two fields that exists in the synchroscope when the second engine is running faster than the master engine. The frequency of the single-phase flux is higher than the frequency of the 3-phase flux, and the rotating field will have moved less than 180 degrees when the vane polarity has changed from maximum north to maximum south. The rotor will turn clockwise at a speed great enough to make up for the difference in frequency between the two fluxes.

For the typical arrangement of 4-pole rotors in generators driven at one-half engine speed, the synchroscope rotor will turn at a speed equal to the difference between the speeds of the two engines. For other arrangements, the synchroscope rotor will turn at a speed proportional to the difference between the speeds of the two engines. The pointer at the end of the rotor shaft, therefore, gives a visual indication of the condition of synchronism that exists between the two engines in question. To synchronize an engine with the master engine, all the pilot need do is to note whether it is running too fast or too slow, as indicated by the direction of rotation of the synchroscope pointer and the markings on the instrument dial, and adjust its speed accordingly until the indicator pointer becomes stationary.

Design Features

Panel space is at a high premium in present day aircraft, and it is very desirable and necessary to reduce the amount of panel space occupied by any instrument. For the synchroscope this has been accomplished by an unusually compact instrument-mechanism design. Figure 7 shows three synchroscope mechanisms in a $1^7/_8$-inch diameter case to provide synchronism indication for 4-engine planes. Figure 8 illustrates five synchroscope mechanisms in a $2^3/_4$-inch diameter case for 6-engine aircraft. If desired, a single mechanism can be used with a selector switch in any multiengine airplane, or it may be incorporated in a dual tachometer indicator.

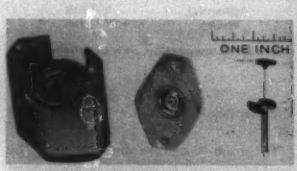


Figure 9. Disassembled view of synchroscope mechanism showing top of 3-phase winding, top bridge, and rotor assembly

Simplicity of construction and mechanical sturdiness are desirable features for aircraft instruments. These features are illustrated by Figure 9 which shows a disassembled synchroscope mechanism. Placing both windings on the stator, thus eliminating brushes and all other connections to the rotor, permits the synchroscope to be built strongly and yet simply enough to allow easy disassembly. Less than five minutes are required, using only a small screwdriver, to take apart and reassemble the complete mechanism.

Operating Characteristics

Two primary operating characteristics determine how satisfactory a synchroscope is for aircraft applications.[4] First, the rotor should begin to turn when the differential speed between the two engines being synchronized is 150 rpm or more over an engine speed range of 1,400 to 4,500 rpm. It should continue to rotate

until this differential speed has been reduced to zero. Second, when the rotor is turning, it should rotate smoothly, especially when the differential speed is 5 rpm or less.

Smooth operation is dependent on two characteristics of the synchroscope. The natural period of oscillation of the system, made up of the rotor mass and the magnetic coupling between the vane and the rotating 3-phase field, must be above the maximum speed at which the instrument is to operate. The strength of the 3-phase field must be uniform around the periphery of the 3-phase winding. If these conditions do not exist, erratic operation of the rotor assembly will occur. By keeping the moment of inertia of the rotating system as low as possible, and by using a toroidal construction for the 3-phase core and coil assembly as previously described, smooth operation is obtained.

Figure 10 shows typical starting characteristics of a synchroscope built according to the design previously discussed. Small magnetic irregularities in the instrument add to the starting torque in one direction and subtract from it in the opposite direction. For this reason, the starting characteristics vary slightly, depending on the direction in which the rotor is turning.

Figure 10. Starting characteristics of synchroscope at room temperature

A—Rotor turning clockwise
B—Rotor turning counterclockwise
C—Average of *A* and *B*

Figure 11 shows the starting characteristics of the synchroscope at high and low ambient temperature. The torque exerted on the rotor vane is an inverse function of the temperature of the synchroscope windings, as the resistance of the coils is a direct function of their temperature.

To keep the windings at a safe operating temperature, and to prevent fogging of the instrument cover glass, the temperature rise in the instrument must be considered. Table I shows these data obtained on a typical synchroscope sample.

Table I

Time, Hours	Room Temp, C	Max Safe Temp Rise, C	Temperature Rise, C			
			Single Phase	Three Phase Coils		
			Coil	AB	BC	AC
0	25		0	0	0	0
1.5	26	40	23	22	25	18

Experience obtained from other instruments indicates that satisfactory service will be obtained at these operating temperatures.

Application Other Than Aircraft

While it has been shown that the synchroscope has a definite aircraft application, its usefulness does not end there. A synchronism indicator such as has been discussed can be used for many other applications where it is necessary to indicate or control the difference in the speeds of two engines.

If 3-phase power is not available, a conventional split-phase[6] design such as is used with some types of single-phase motors can be utilized to operate the synchroscope.

The instrument also can be used as a power-factor or phase-angle indicator when one winding is excited by a voltage in phase with the supply voltage, and the other winding by a voltage in phase with the load current. The position taken by the pointer will be a function of the phase angle between the voltage and current.

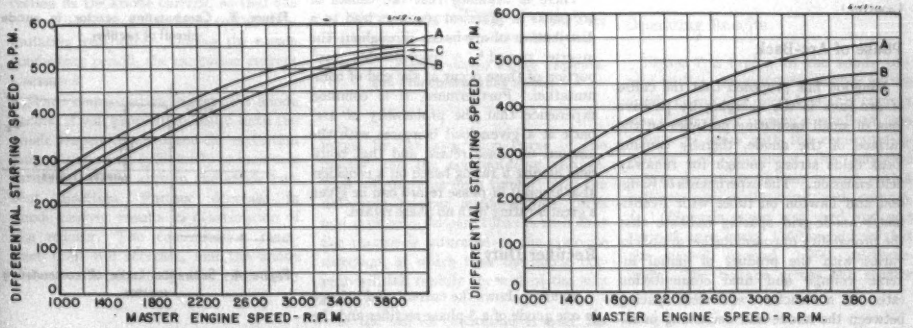
Conclusions

Visual synchronism indication has been shown to contribute appreciably to the satisfactory operation of multiengine aircraft. Improved passenger and crew comfort, lessened vibrational stresses in the aircraft itself, and better flight efficiency are among these contributions.

Characteristics of the synchroscope are simplicity of construction, ease of maintenance, small size, and low weight. These features, coupled with the desirable operating characteristics described previously, make the synchroscope a useful addition to the instrument panels of multiengine airplanes.

Figure 11. Starting characteristics of synchroscope at high and low ambient temperatures

A—Synchroscope at −55 degrees centigrade
B—Synchroscope at +25 degrees centigrade
C—Synchroscope at +71 degrees centigrade



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Nonlinear Commutating Reactors for Rectifiers

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MEMBER AIEE

ONE of the prime objectives in rectifier development during the past 20 years has been the decrease in frequency of arc-back. The factors involved in arc-back have received considerable attention, and it now appears that arc-backs of typical mercury arc rectifiers are caused by the following:

1. Breakdown of the mercury vapor because of inverse voltage.
2. Conditions favorable for cathode spot formation on the anode at the end of the commutation period.

The former cause is not present under normal operating conditions, but may become effective at excessive vapor pressures, as when condensed mercury is permitted to come into contact with a hot anode. The latter cause has been treated in some detail by Kingdon and Lawton.[1]

Phase of Arc-Back

Kingdon has proposed that the cause of arc-back is the charging by positive ions of small insulating particles on the surface of the anode, thereby causing local fields strong enough for runaway field emission. The experiments of Kingdon and Lawton on tubes with 1-centimeter anode-grid spacing indicate that the probability of commutation arc-backs varies with the product of initial inverse voltage and final commutation rate. In a structure with close spacing between the anode and deionizing members, the rate of ion diffusion during commutation is so rapid that the ion density at the end of commutation depends on the rate of change of current at the end of commutation. The number of ions collected by a particle on the anode at the end of commutation determines its resultant potential. This number is proportional to the inverse voltage and the density of ionization.

Hull and Elder have described tests

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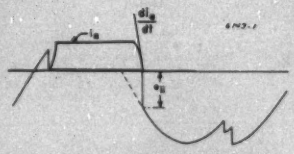

Figure 1. Anode voltage and current in 3-phase rectifier showing elements of rectifier duty

where the factors were controlled so that arc-backs occurred both at commutation and at later times.[2] They concluded that practical rectifiers of correct design will arc-back at the end of commutation rather than some later time, unless conditions are favorable for glow discharge.

There is evidence that the causes of arc-backs in practical rectifiers lead to a distribution of arc-backs throughout the inverse period.[3] A considerable proportion of these occur at the end of commutation. Furthermore, it is common experience that the probability of arc-back at a given load increases with the amount of phase retard and that rectifiers having a rating based on a considerable amount of phase retard can be given a greater rating with no phase retard.

Rectifier Duty

Figure 1 shows the current and voltage in one anode of a 3-phase rectifier and the quantities involved in anode duty. If

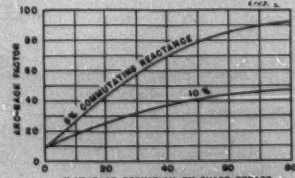

Figure 2. Effect of phase retard and circuit reactance on arc-back factor F_a

$$F_a = e_{ll} \times \frac{di_a}{dt}$$

the effect of residual ionization is denoted by an arc-back factor F_a, then

$$F_a = e_{ll} \times di_a/dt$$
$$= 2\pi f e^2_{ll}/X_c$$

In Kingdon's experiments the frequency of arc-back was approximately proportional to the tenth power of F_a. It will be noted that e_{ll} is an important factor in rectifier duty and that its effect increases rapidly when the rectifier is controlled by phase retard. Figure 2 shows the effect of phase retard on the arc-back factor. Increase of commutating reactance results in a decrease in rectifier duty. This is not a desirable means for reducing duty as increase in reactance results in

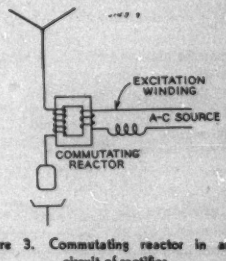

Figure 3. Commutating reactor in anode circuit of rectifier

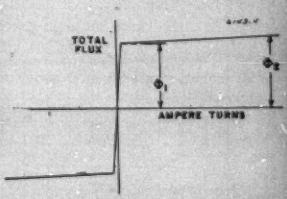

Figure 4. Saturation curve of commutating reactor

increased rectifier regulation and reduced power factor. If the anode current can be "dragged out" or maintained at some low value for a sufficient period just before the end of commutation, a substantial reduction in residual ionization and arc-back probability should result.

Action of Commutating Reactor

A commutating reactor is defined as a reactor used primarily to modify the rate of current transfer between rectifying elements.

A closed core anode reactor having an a-c excitation winding, as shown in Figure

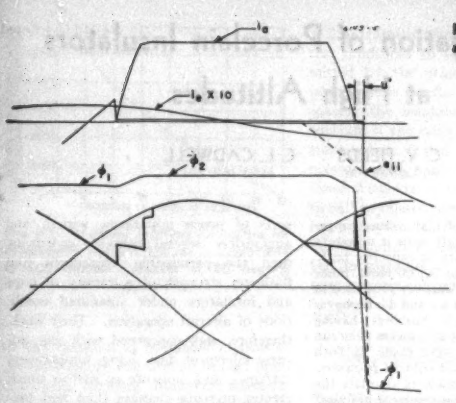

Figure 5. Circuit action of commutating reactor

3, may be used to "drag out" the anode current. Such a reactor preferably would have high permeability below saturation and little flux change beyond saturation, as shown in Figure 4.

Figure 5 shows the circuit action of the reactor. When anode conduction begins, the reactor already is saturated by the excitation winding in the same direction as the anode current, so that the reactor adds relatively little to the commutating reactance. During the anode conducting period, the excitation current i_e reverses.

When commutation to the next anode occurs, it will proceed normally until the anode ampere turns exceed the excitation ampere turns just sufficiently to maintain saturation of the core in the anode current direction. Further decrease in anode current results in desaturation of the reactor. The commutating reactance then will increase, and the anode current will fall slowly at a rate determined by the saturation curve of the reactor and the commutating voltage. This will continue for a time u' until the difference between anode ampere turns and excitation ampere turns is such that the reactor is saturated in the opposite direction, at which time the anode current will fall rapidly the rest of the way to zero.

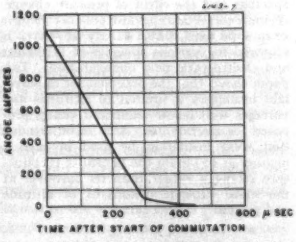

Figure 7. Anode current during commutation with commutating reactor

If the reactor excitation is near the knee of the saturation curve, so that the "drag out" period u' ends at a low value of anode current, then the residual ionization at the end of the conduction period will be reduced. The amount of reduction will depend on the time u'. The value of u' which is needed depends on the arc-back factor and the rate of ion cleanup, which is a function of the geometry of the anode and grid structure of the rectifier.

Design of Commutating Reactors

The relation $2n\phi_1 \times 10^{-8} = u' \times E_c$ determines the product of anode turns and core section of the reactor. Optimum design requires a minimum ratio of maximum flux to saturating flux in order to reduce the regulation caused by the reactor. The direct voltage loss caused by the reactor is given by

$$E_{xc} = npf(\phi_3 - \phi_1) \times 10^{-8}$$

Since a complete flux reversal occurs in a few electrical degrees, a core design with low eddy loss is needed, otherwise the iron heating will be high and a portion of the drag out period will be consumed in setting up eddy currents in the core structure.

Reactor excitation may be obtained from a separate a-c source, as shown in Figure 3. In this case an impedance is needed in the excitation circuit to limit coupling between the anode circuit and the excitation circuit during the period u', when a high voltage may be induced in the excitation winding. Excitation also may be derived from the currents in other anodes, as shown in Figure 6. If the number of turns in the main winding is so small that this arrangement produces too many excitation ampere turns, suitable current transformers may be used between the anode circuit and the excitation winding.

Operating Results

Figure 7 is typical of the anode current with a commutating reactor in the anode circuit. A record of this current was obtained by placing a small air core reactor in series with the commutating reactor and measuring the amplified voltage across the air core reactor with a cathode ray oscilloscope and camera. A 1,000-cycle sweep was used and was tripped once every 1/60 second so that the record covered 1,000 microseconds. The voltage across the reactor

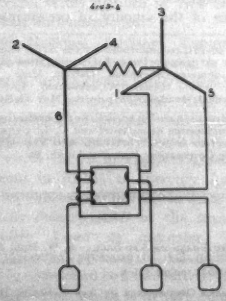

Figure 6. Commutating reactor with excitation by anode currents

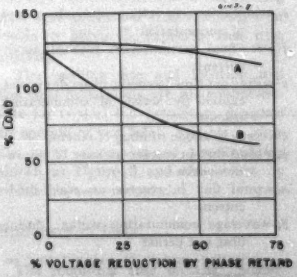

Figure 8. Short time rating of rectifier

A—Commutating reactors
B—No commutating reactors

is proportional to the rate of change of anode current. Since the current at the beginning of commutation was known, the current during commutation could be calculated from the measured rate of change.

Figure 8 indicates the gain resulting from the use of commutating reactors when considerable phase retard is employed. Curve *A* taken with commutating reactors with a drag out time of 350 microseconds at 70 per cent voltage reduction shows that no reduction in rating is needed for phase control. However, a reduction of 40 per cent in rating must be applied in going from 15 to 70 per cent or more voltage reduction without reactors. This is shown in curve *B*. The base load for these curves is the maximum load that can be carried with 15 per cent voltage reduction for a definite time without arc-back.

In this instance it is seen that commutation arc-backs limit the rectifier load both at full and reduced voltages. A minor gain is realized by the use of commutating reactors at full voltage. This becomes a major gain where considerable voltage control is required.

Conclusion

Present day applications of rectifiers call for increasing amounts of voltage control, in many cases to zero voltage. Sustained operation of a rectifier with considerable voltage control usually requires derating of the rectifier. The use of commutating reactors eliminates such derating. They also may prove useful for other cases where high rates of commutation are involved, as at frequencies above 60 cycles.

Appendix. Nomenclature

e_{it} = initial inverse voltage of anode at end of commutation
di_a/dt = final commutation rate of anode current
u' = drag out time (seconds) of anode current caused by action of commutating reactor
n = turns in anode winding of reactor
ϕ_1 = total flux in reactor at knee of saturation curve
ϕ_2 = total flux in reactor at peak anode current
E_c = average commutating voltage during drag out period
i_e = excitation current in commutating reactor
X_c = commutating reactance per phase
p = number of phases in simple rectifier
f = frequency, cycles per second

Investigation of Porcelain Insulators at High Altitudes

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Synopsis: The use of high voltage apparatus in military aircraft made it necessary to obtain flashover data on capacitor bushings at altitudes up to 50,000 feet. Some of the more pertinent data are presented in this paper which gives a-c and d-c flashover voltages for porcelain bushings having spacings of 5/8 inch to 2 7/8 inches from cap to ring. The tests were made at both normal atmospheric and reduced pressures, but no attempt was made to simulate the frosting conditions as encountered in flying. Correlations are shown between bushing spacings and the effect of pressure change. A single correction curve for pressure changes cannot be used, but a family of curves is required for various spacings of insulators and electrostatic field configuration. This paper shows that the practical use of porcelain insulators is limited to altitudes and voltages well below maximum values proposed for aircraft use. It is recommended that solid insulation be used in such a manner as to obtain the benefit of its puncture strength rather than its flashover at the more extreme conditions of altitude and voltage.

UNTIL RECENTLY the low pressure flashover strength of communication apparatus bushings has received little attention. Previous work, such as that reported by Bellaschi and Evans,[1] covers large gaps and insulators as related to power system operation. More fundamental studies of air strength between various gaps at low air density have been presented by Peek[2] and by Schwaiger and Sorensen.[3]

At the beginning of the war, ignition systems were the chief concern and became rapidly more important with increasing altitudes and severity of operating conditions.[4] This problem was solved by proper use of solid insulating materials.

Concurrently, the tremendous increase in air-borne electric apparatus and the subsequent increase in aircraft distribution voltages brought on many practical problems relative to the operation of all sorts of power apparatus, wiring, and auxiliaries. Several authors[5,6] have measured the permissible breakdown and flashover strength of a variety of gaps and insulators under simulated conditions of aircraft operation. Their work, therefore, was concerned with the adverse affects of dust, icing, temperature extremes, and moisture as well as much greater pressure changes than had previously been studied, and for relatively low voltages only.

Toward the end of the war, certain high voltage air-borne apparatus, particularly radar and communication equipment, began to offer new electrical problems unlike any phase of the previous work. The flashover strength of transformer and capacitor bushings, vacuum tube sockets, and similar apparatus became a major problem. After a cursory investigation, it became apparent that size and weight of insulators required was such that it was impractical to insulate apparatus for voltages over about 5,000 volts at stratosphere aircraft operating conditions, which not only include extreme altitudes, but very rapid changes in temperature and altitude with accompanying moisture condensation.

Pressurization of cabins and apparatus compartments has been accepted as the most satisfactory means of reducing the weight of very high voltage apparatus. There remain, however, many marginal conditions where pressurization may be advantageously or necessarily avoided. Choice of the amount of pressurization

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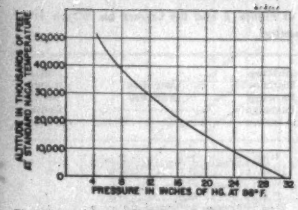

Figure 1. National Advisory Committee for Aeronautics standard altitude corresponding to test chamber pressures at 86 degrees Fahrenheit

or the question of operation in case of pressure failure will depend in part upon apparatus bushing flashover strength. Commercial aircraft will continue to operate at moderate altitudes where pressurization is not warranted. Television and radio equipment will be operated in increasing quantities at moderately high elevations where consideration of the reduction in flashover strength of apparatus bushings caused by reduced pressure will be required.

Previously reported observations of the effects of condensation and frosting on low voltage systems[4] are generally applicable to the high voltage bushings discussed in this paper. That is, unless there is moisture condensation on bushing surfaces, variations in humidity do not affect the breakdown appreciably. Neither is the breakdown affected by frozen moisture. It is to be noted that such factors are of less importance in commercial applications where variations are neither as extreme nor as rapid, and moisture condensation, therefore, less likely to occur. The present work is concerned primarily with the effects of pressure change. All tests were made at room temperature with normal variations in humidity. Omission of a humidity correction seems justified in view of the previous work mentioned.

The National Advisory Committee for Aeronautics standard pressure, temperature, and altitude table generally is accepted for aircraft work. This table gives a standard pressure and a corresponding temperature for each elevation. The curve shown in Figure 1 gives the pressure in inches of mercury (at 86 degrees Fahrenheit) having the same relative air density *RAD* as the standard altitudes shown as ordinates. Thus the measured pressure of 4.7 inches is seen to correspond to a standard elevation of 50,000 feet, which is in turn equal to 3.4 inches of mercury at the standard temperature of −66 degrees.

This transition from room temperature test conditions to high altitudes is permitted by the principle of similitude,[2] which states in effect that for constant spacing the breakdown voltage will be constant if the ratio of P/T is kept constant, where P and T are the absolute pressure and temperature respectively. Since flashover is substantially proportional[3] to relative air density, the following expression may be used to convert our manometer readings taken at the test temperature of 86 degrees to other temperatures and pressures:

$$RAD = \frac{17.95 \times \text{barometric pressure (inches)}}{460 + \text{temperature (degrees Fahrenheit)}} \quad (1)$$

Test Equipment and Procedure

Most low pressure work previously reported has been conducted with the specimens in a nonmetallic container to reduce field distortion to a minimum. Since it is desirable to test bushings in their normal position mounted on the capacitor, we found it necessary to use a relatively large test chamber. Also, since capacitors usually are surrounded by metal surfaces in practice, it appeared logical to use a metal rather than a glass chamber used by some previous workers testing bushings alone. Capacitor specimens were placed approximately in the center of the tank.

The high voltage lead was brought into the tank through a single hole in the center of the 7/8-inch thick glass cover. The capacitor case was grounded to the tank in bushing-to-ground tests, while the case was insulated and one bushing was grounded for the bushing-to-bushing tests.

The direct voltage was supplied through a 175,000-ohm resistor by a well-filtered rectifier source. A voltmeter was connected directly across the specimen and a dip in the voltmeter reading was taken as the breakdown point. The current was so limited that no apparent damage occurred to the specimen, and a large number of successive readings could be taken without reduction in flashover strength.

The a-c tests were taken on two standard test sets, each with a tertiary voltmeter winding. All points under 50 kv were obtained with a 5-kva 50-kv test set using a hand operated induction regulator. All points above 50-kv were taken with a 50-kva 100-kv test set with a motor driven induction regulator. The wave form conformed to the ASTM Standard D 149.

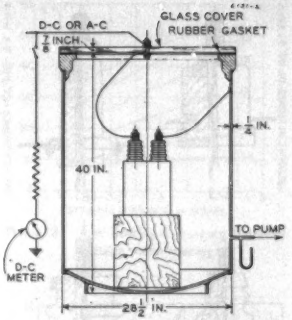

Figure 2. Apparatus for determining capacitor bushing flashover in air at various pressures

Both alternating and direct voltages were raised uniformly at a rate of approximately 10 kv per minute except in the case where the motor driven test set was used, the voltage of which was raised 3 kv per second.

Pressures were measured by a closed tube manometer and a pressure gauge calibrated in inches of mercury absolute. Corresponding altitude values may be obtained by reference to Figure 1 as explained.

Bushing Specimens

These tests were conducted on six typical capacitor bushings shown in Figure 3. All except the gasket sealed bushing *A* were of the "Solder-Seal" metal to porcelain type. They were mounted on conventional capacitor cases with working elements omitted. Leads attached to the top of the bushings were allowed to assume normal positions touching the inside walls of the bushing at random. The leads were clipped off one inch below the bottom of the bushing and were prevented from flashing over inside by filling the capacitor case with Inerteen.*

The bushing size and location and the case dimensions are all commensurate for typical d-c capacitors designed to operate at sea level. Table I gives the major dimensions of the bushings shown in Figure 3 and the covers on which they were mounted.

Summary of Data

The mounting ring on the "Solder-Seal" bushing presents a smooth well-rounded surface, while the cap has rela-

*Chlorinated diphenyl.

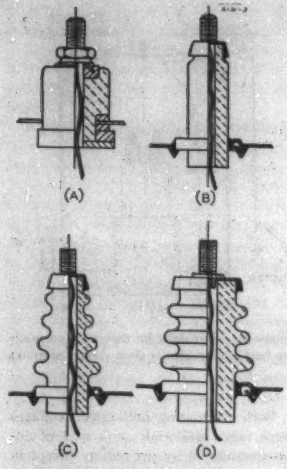

Figure 3. Capacitor bushings tested
Dimensions are shown in Table I

Table I. Major Dimensions of Bushings Shown in Figure 3 and the Covers on Which They Were Mounted

Bushing	Figure	Flashover (Tight-String) Distance in Inches	Diameter (Maximum) in Inches	Striking Distance Between Bushings in Inches	Case Size in Inches		Distance Between Bushing Centers in Inches
					Length	Width	
A	3A	31/32	5/8	12/32	2 1/8	1 3/32	1 1/8
B	3B	1 5/32	5/8	1 15/32	3 3/8	1 5/8	2
C	3B	1 7/8	13/32	1 1/32	3 3/8	1 5/8	2
D	3C	2 1/32	1 1/8	25/32	4 9/32	3 5/8	2
E	3D	2 9/32	2 3/8	2 9/32	8	4	4 1/8
				4 25/32	13 1/8	4 3/8	6 3/4
F	3D	2 13/32	2 3/8	2 9/32	8	4	4 1/8
				4 13/32	13 3/8	4 3/8	6 3/4

* Bushing *E* is similar to *F* except that the former has only two corrugations.

tively sharp edges but no burrs. Nevertheless, most streamers seem to form on the lower ring, and breakdown voltages seem relatively unaffected by rounding of the edges on the cap. This suggests that the high field intensity at the base of the bushing was a controlling factor in the breakdown mechanism. Most flashovers were observed to occur between the cap and the mounting ring at 1/16 inch or more from the porcelain and rarely seemed to follow the bushing surface.

The bushings tested differ in form as well as height; however, each is of typical configuration for its height. It seemed logical, therefore, to plot curves as a function of height although it is known that the breakdown is partially dependent on diameter and shape. To have all bushings straight sided and of one diameter would make the test academically correct, but of less practical value. Tight-string distance was measured between cap and mounting ring.

No special efforts were made to avoid ordinary variations in the height of liquid or position of the wire inside the bushings, or other normal factors affecting the breakdown voltages. The relatively large spread in flashover, compared to sphere gaps tested in a uniform field, attests to the effect of these variables. Especially at very low pressures, these normal variations in construction may cause unexpectedly large variations in flashover. The data are sufficiently consistent to warrant drawing the curves shown, but seemed to indicate the desirability of testing capacitors or similar apparatus at actual working pressures.

Bushing to case flashover tests were made first on all six bushings with a-c and both polarities of direct voltage. The data in Figure 4 were obtained by evacuating the chamber, then making a series of tests at four or more pressures, each time admitting air to obtain the pressure desired and taking at least five flashover readings after the pressure had become stable at the new value. All points were plotted and smooth curves were drawn through them. Similar smooth curves were drawn for a-c and positive d-c tests on each bushing. However, only the data for the d-c negative flashover tests are shown since they happen to be more conservative at the lower pressures than the values obtained for the d-c positive flashover tests.

Points corresponding to each of the pressures on the curves of Figures 5 and 6 were taken from the smooth curves drawn through the original test points. These latter curves of flashover versus striking distance, therefore, ignore differences between the various bushings, but show clearly how spacing affects flashover at the various pressures. From these curves it is seen to be increasingly difficult to develop high flashover voltage by increasing the bushing size at greatly reduced pressure. The curve for 4.7 inches of mercury clearly illustrates why about 5,000 volts is a logical maximum voltage for any apparatus bushing operated at or near 50,000 feet. An enormous increase in bushing size would be required to double the flashover voltage.

It is noted that the crest a-c values are somewhat lower than either positive or negative d-c breakdown values at

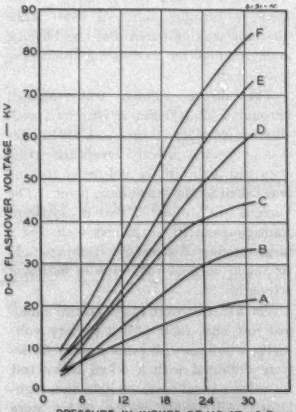

Figure 4. Negative d-c flashover-pressure curves for six bushings tested
Dimensions are shown in Table I

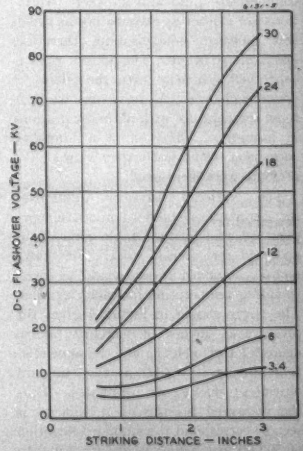

Figure 5. Negative direct voltage required to flash bushings over to case

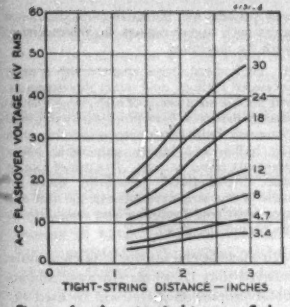

Figure 6. A-c terminal-to-case flashover voltage

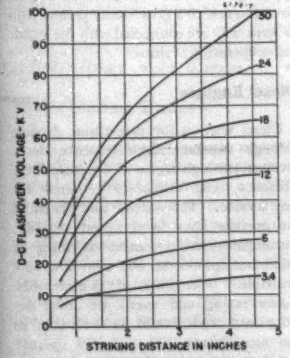

Figure 7. Negative d-c bushing-to-bushing flashover versus spacing

high pressures. This discrepancy is contrary to Berberich's experience in which the peak a-c is higher than d-c values.[5] It is believed that this apparent discrepancy is caused by differences in configuration, both of the field and of the bushings themselves.

A second set of tests was made with the same capacitor bushings mounted as described previously, except that the voltage was applied from bushing to bushing instead of from bushing to case. The flashover values are shown in Figures 7 and 8. Electrostatic fields were assumed to be largely responsible for the considerable rounding of these curves at large spacings.

In order to check the possible relationship between sphere gaps, point gaps, and bushings, the curve in Figure 9 was drawn. From this curve it can be seen that while sphere and point gap flashovers are practically straight lines at sea-level, they flatten out considerably at lower pressures. The bushing to bushing flashover values at 3.4 inches of mercury are intermediate between point and sphere gap values, as might be expected. However, one would not expect the bushing flashover values to fall below those of a point gap. This peculiarity also is believed to be caused by nonuniformity of the field surrounding the capacitor bushings. This explanation is substantiated by a wide variation in flashover voltages of several bushings spaced about the same distance apart, but of different heights.

Ratios of from three to five between sea-level and 45,000-foot altitude flashover voltages found in our work are higher than the 2.7 to 3.7 ratios found by DeLerno[4] in working with smaller gaps.

Table II gives the d-c rated voltage of several capacitors and the flashover voltages taken from the curves for bushings of a size which one would expect to use for high altitude operation. As can be seen, the actual flashover voltages at 45,000 feet are well above the rated values. For comparison, a column is added showing the sea-level test voltage of twice the rated voltage, times 3.7, plus 1,000 volts. It is obvious that the substitution of our maximum ratio of 5 for the 3.7, giving ten times rated voltage plus 1,000 volts, would be nearer the actual sea-level flashover of these particular bushings. However, such a rule would have to be qualified to account for the change in ratio which increases rapidly at large spacings. Furthermore, these sea-level voltages are far higher than could be withstood by the solid insulation used in practice on most apparatus.

Conclusions

1. Our investigations indicate that changes in flashover voltages do not vary in any simple manner with changes in pressure. Ratios of low pressure to high pressure flashover voltages vary considerably with bushing size and configuration, surrounding field, and other factors so that very definite relationships cannot be established.

2. Since the sea-level flashover voltage of most bushings designed for operation at 50,000 feet is far higher than can be withstood by the solid insulation of the apparatus, it appears best to test the completed apparatus in a low pressure chamber to assure proper safety factors at high altitudes. This is particularly true for capacitors because the location of the lead wire and the height of the liquid inside the bushing, and other factors markedly affecting the field change the flashover, especially at very low pressures.

3. The flashover voltage-distance curves for very high altitudes (50,000 feet) are so flat that it is apparent that no reasonable spacing will permit the use of bushings or

Table II. Flashover and Test Voltages for Several High Altitude Capacitor Bushings

Rated Direct Voltage	Bushing Flashover Voltage Distance in Inches	Expected Flashover Voltage at 45,000 Feet*	Actual Flashover Voltage at Sea-Level	Twice Rated Voltage Times 3.7 Plus 1,000 Volts
1,500	13/32	7,000	25,000	12,000
3,000	1 5/16	7,500	33,000	23,200
5,000	1 25/32	10,500	57,500	38,000

* Computed for NACA standard altitude from curves taken at 86 degrees Fahrenheit.

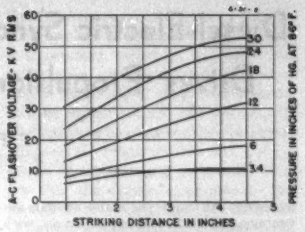

Figure 8. A-c bushing-to-bushing flashover voltage versus spacing

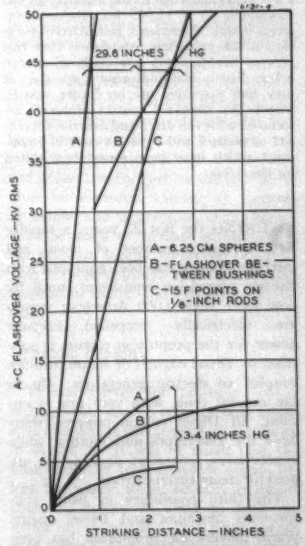

Figure 9. A-c bushing-to-bushing flashover voltages showing relationships to sphere and point gaps with corresponding spacings

Diesel-Electric Synchronous Motor Ship Drives—Propulsion Control Problems

E. FRISCH
NONMEMBER AIEE

Synopsis: Although the many obvious advantages of ship propulsion drives with synchronous motors and generators, and with power supplied by Diesel engines, have been realized for some time, no actual installations were made in this country until a few years ago when a trial installation was completed on a 12,000 horsepower twin-screw vessel. Experience gained from operation of this vessel has established that this type of drive in many respects is superior to other drives, and indications are that it may find extensive use on future vessels. The paper discusses control problems associated with the drive and describes methods of control and types of control equipment which have been found best suited for the drive.

DURING the last 25 years, a rapidly increasing number of naval and merchant vessels has been equipped with electric propulsion equipment, until by now more than 2,000 American vessels are electrically propelled. Primary power for the propulsion motors is supplied by Diesel engines or steam turbines coupled to electric generators. Up to the present time, with very few exceptions, all Diesel engine powered ships have d-c generators and motors, while synchronous generators and motors are used for steam-turbine drives.

The third possibility of using synchronous machines and Diesel engine prime movers for propulsion has been under considerable discussion for years. This type of drive has many obvious merits, but anticipated operating difficulties, especially during maneuvering, delayed actual installations on American vessels for several years. Finally in 1940, with the encouragement of various manufacturing concerns, plans were prepared and an order placed for a trial installation on a twin-screw vessel to demonstrate the practicability of the drive.

The vessel, which was completed in 1942, has two 5,900-horsepower 2,400-volt 3-phase synchronous propulsion motors. Power is supplied by eight 1,600-horsepower Diesel engines direct connected to 1,150-kva generators. The experience gained during sea trials and, through actual operation of the vessel for three years has proved conclusively that this type of drive not only is practical but in many respects is superior to similar drives using d-c equipment. There also is a good possibility that it may offer strong competition to turbine-electric drives for many applications.

Among the advantages of the drive, the following can be mentioned:

1. Synchronous machines weigh less and cost less than d-c machines of the same rating and their efficiency is higher.

2. Synchronous machines are more reliable and easier to maintain than d-c machines.

3. Machines with higher voltage can be used, thereby causing a reduction in cables and bus bars and permitting installation of units with higher ratings than is practical with d-c machines.

4. High speed Diesel engines with greatly increased ratings, now under development, will permit installation of high power Diesel-electric drives on vessels ordinarily powered by steam turbines, thereby dispensing with the bulky and highly vulnerable boiler plants on these vessels. The use of two or more Diesel-electric generating units instead of one larger turbine-electric unit will give additional flexibility and reliability to the propulsion drive.

In view of the above, it is commonly believed that Diesel-electric synchronous motor propulsion drives will be used extensively on future electrically propelled vessels. A brief discussion of problems, type of equipment, and method of control applying to the drives, therefore, should be of interest to a great many people who in some way are connected with the building or operation of ships.

Diesel Engines

Diesel engines for propulsion service, through constant improvements, have attained the high degree of dependability, efficiency, and durability required for this service. The output and speed of the engines have been raised steadily, and engines with a continuous rating of 2,000 horsepower at 800 rpm are now available. Engines of considerably higher rating and speed are under development and should be available in the near future. The engines operate satisfactorily at speeds as low as 30 per cent of rated speed. They develop rated torque down to 50 to 60 per cent speed, but at lower speeds the torque will be reduced gradually to as low as 60 per cent of rated torque at 30 per cent speed.

The engine speed is controlled by governors of the hydraulic type. As a protection against overloading, the governors will automatically limit the amount of fuel which is admitted to the engine per stroke. This amount decreases at low speeds so that the maximum torque, at any speed, will not exceed a safe value for continuous operation. If the torque is exceeded the engines will slow down and unload themselves.

The speed of the engines is adjusted remotely from the propulsion control board. A master speed control transmitter, coupled to the speed lever, serves

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air insulation appreciably above 5,000 volts. Connectors taking advantage of solid insulation puncture strength, similar to those used in aircraft ignition systems, should be developed if higher voltages are encountered at extreme altitudes.

4. The curves shown represent the conservative averages of a great many tests made under practical conditions, and it is believed that they will serve as a guide in the selection of porcelain bushings falling within the scope of our work.

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to position receivers on the engine governors. Pneumatic or electric positioning devices are available for the speed control. Since the engines must operate in parallel at the same speed, means must be provided to equalize the engine loading. This may be performed automatically or by means of manual vernier speed control transmitters on the control board.

Starting and reversal of the propulsion motor are performed with the engines running at minimum speed. For satisfactory performance the engines must develop the highest possible torque during this period. The torque limitation, imposed on the engines by the governor action, therefore, is removed by energizing of magnetic solenoids provided on the engine governors for this purpose. This will raise the engine torque to a maximum value on the order of 85 per cent of rated torque, which can be delivered for short periods without causing damage.

Motor Starting Torque

During maneuvering periods, when the propulsion motor is being started or reversed, the motor operates as a squirrel cage induction motor with the de-energized field connected in series with a starting resistor. To develop the necessary starting and synchronizing torque, the motor must be provided with heavy damper windings and the associated generators must be overexcited with 200 to 300 per cent normal field current. The motor torque is a combination of two individual components. One component is produced by the current induced in the damper winding while the other component is produced by the current induced in the field coils. The value of the latter component is a function of the value of the starting resistance.

Typical curves, representing the two torque components and the resultant torque as a function of the resistor value, are shown in Figure 1 for 30 per cent generator speed. It will be noted that the peak value of the field torque components *B*1, *B*2, and *B*3 is practically independent of the resistor value but occurs at different motor slips. The starting resistor value should be selected so that a maximum resultant motor torque will be developed at the highest motor slip at which successful synchronizing is possible. The resultant torque curve *C*2 fulfills this requirement. Under certain conditions it may be necessary to bring the motor up to a maximum speed with one resistor value, and then increase the speed further by shorting out part of the resistor before synchronizing is possible. The peak value of the combined torque occurs at 35 to 50 per cent motor slip and should not be less than 50 to 60 per cent of full load torque when all generators are in service and overexcited.

Torque Margin

Torque margin for an electric propulsion drive is defined as the difference between the torque required by the propeller for normal full power running and the torque at which the motor pulls out of step, expressed as a percentage of the propeller torque.

For Diesel-electric drives, a torque margin of 10 to 15 per cent at normal generator and motor excitation is sufficient. This low torque margin is permissible because of the torque limiting feature of modern engine governors. When operating the vessel in rough weather or during periods of acceleration the propeller torque requirement frequently exceeds the pull-out torque.

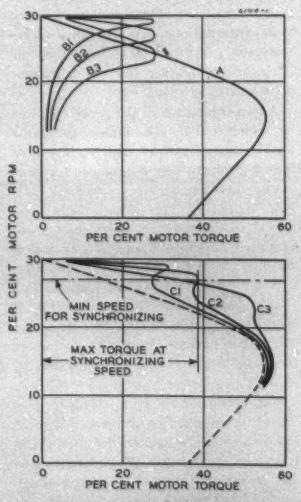

Figure 1. Curves showing the starting torque of a synchronous motor as a function of motor speed for different values of starting resistance

A—Torque developed by damper winding
B—Torque developed by motor field winding
*B*1—Low starting resistance
*B*2—Medium starting resistance
*B*3—High starting resistance
C—Total motor torque
*C*1—Low starting resistance
*C*2—Medium starting resistance
*C*3—High starting resistance

Since the engines cannot develop a torque of this value, however, the result is only a momentary reduction in engine and motor speed and a corresponding reduction in the propeller torque requirement, but the motor will not pull out of step. The transient increase in propeller torque builds up at a relatively slow rate, and the inertia of engines and generators is so low that the engine speed reduces fast enough to prevent the actual occurrence of torques higher than the pull-out value.

This is in contrast to conditions encountered on steam turbine drives. The torque developed by a turbine cannot conveniently be limited by governor action, and may easily exceed rated torque. Furthermore, the turbine inertia is relatively high and its speed cannot be reduced fast enough to prevent occurrence of transient torques, exceeding the pull-out torque, even though the turbine torque was limited. For this reason, the torque margin built into motors and generators for turbine-electric drives must be increased, causing an increase in weight and dimensions, or provisions must be made to increase automatically the pull-out torque whenever required. This is accomplished by a momentary increase in motor and generator excitation.

Dynamic Braking

Typical curves for propeller torque requirements during reversal of a vessel with four propulsion generators are shown in Figure 2. It will be noted that the peak propeller torque, which occurs before the motor stops, actually is higher than the torque required to hold the motor at standstill. This peak torque is of particular interest because it occurs at a point where the available motor torque is low and, in most instances, is not sufficient to overcome the peak torque.

To illustrate this condition, a series of curves representing the available motor torque for two, three, and four generators, operating at 30 per cent speed, have been shown for comparison. Examination of the curves discloses that the propeller cannot be stopped by motor torque alone, even with four generators in service, and that the condition is equally adverse for 2-generator operation, although the propeller torque is reduced, as a result of the lower ship speed in this case.

To stop the propeller preparatory to a reversal, two methods are available:

1. Permit the vessel to slow down without power on the motor until the propeller torque is reduced below the corresponding motor torque at all speed points, and then

apply reverse power. The time required for the slow-down, however, is excessive, especially for large vessels, and this method is not acceptable.

2. Stop the motor by dynamic braking. By this means the motor can be brought to practically standstill and reverse power applied in a few seconds. Since the additional equipment, required for dynamic braking, is relatively inexpensive, this method should be incorporated on all drives of this type as a means for reducing the time required for motor reversal.

Dynamic braking of the motor is produced by connecting a 3-phase resistor to the motor terminals and energizing the motor field with normal field current. The effect of the value of the braking resistance on the braking torque is illustrated in Figure 3, where curves are shown for braking torque as a function of motor speed for three different resistance values. It will be noted that the value of the peak braking torque is practically independent of the resistance value. However, the torque peak occurs at a higher motor speed when the resistance value is increased.

The propeller torque curve for maximum ship speed also is shown to illustrate the relation between this torque and the braking torque. The points of intersection of the curves give the minimum value to which the motor speed will be reduced for different values of braking resistance. The speed decreases with decreasing resistance value. For very low resistance values, however, the braking torque is not sufficient to overcome the propeller torque at higher motor speeds, as illustrated by curve *A*1, and the motor speed will not be reduced below speed *C*. This must be kept in mind when designing the starting resistor, and a check should be made to ascertain that the braking torque is higher than the motor torque at all speeds, as illustrated by curve *A*2.

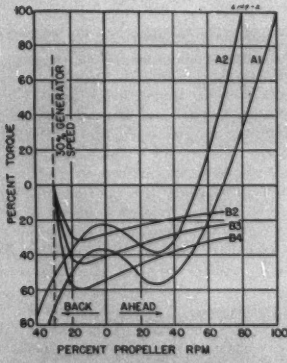

Figure 2. Curves showing motor and propeller torque as a function of motor speed during reversals, vessel moving at full speed ahead

*A*1—Propeller torque, four generators in service
*A*2—Propeller torque, two generators in service
B—Torque developed by propulsion motor
*B*2—Two generators in service
*B*3—Three generators in service
*B*4—Four generators in service

General Control Scheme

A complete propulsion plant consists of two or more Diesel engines directly connected to synchronous generators, a synchronous propulsion motor, an excitation supply, and the propulsion control equipment.

The method of control is very simple and should not vary greatly for different installations. The general description given in this paper gives a fairly complete picture of the type of equipment, control scheme, and operating procedure for most installations. A simplified schematic diagram of a typical control scheme is shown in Figure 4 for a synchronous drive with three generators.

Any combination of the generators can be connected to a common generator bus by means of three high voltage contactor groups. The contactors for generator number one are numbered 1*G*1, 1*G*2, and 1*G*3. The motor can be connected to the same bus by means of reversing contactors *R*1 to *R*4, of which *R*2 and *R*3 close for "ahead" operation and *R*1 and *R*4 close for "astern" or "back" operation. Quick stopping of the motor is made possible by connecting a dynamic braking resistor to the motor terminals by the closing of contactors *R*5 to *R*7.

The excitation for the propulsion machinery is supplied by a motor-generator set with separate exciters for motor and generator excitation. The exciter fields are energized from a constant voltage control bus through a magnetic field contactor *F*, which remains closed for normal operation. The generator and motor exciter fields are energized by the closing of starting switches *S*4 and *S*6. The generator and motor fields are connected to the associated exciter busses by means of field switches as shown. When a field is de-energized, it is connected to a discharge or starting resistor to prevent high inductive voltage peaks.

The cooling of the field coils becomes less effective when the speed of the propulsion motors and generators is reduced. The exciter voltage, therefore, must be decreased for low speed operation, by means of rheostats in the exciter field circuits, to prevent overheating of the coils. The rheostats are coupled to the speed control lever, and so designed that the exciter voltage will be reduced to approximately 75 per cent of normal when the speed lever is moved from the "fast" to the "slow" speed position. The rheostats are shorted by means of starter switches *S*5 and *S*7 during the starting period when maximum excitation is needed to obtain the required starting and synchronizing torques. The generator exciter voltage must be raised to 200 to 300 per cent of normal during this period. A resistor is connected in series with the generator exciter rheostat to reduce the exciter to voltage to normal when switch *S*5 opens in the "run" position.

For the sake of simplicity it is assumed that all contactors and switches, shown in the diagram, are of the cam operated type arranged in groups and controlled manually by means of operating levers in a control stand at the front of the control board. A diagram of the control stand is shown in Figure 5.

Incorrect operation of the starting levers is prevented by means of mechanical interlocking as indicated in the lever diagram. The purpose of the interlocking is as follows:

1. The motor speed lever and the starter lever are interlocked to prevent starting of the motor unless the engine speed is a minimum. It also is necessary to reduce the speed to a minimum before stopping the motor.

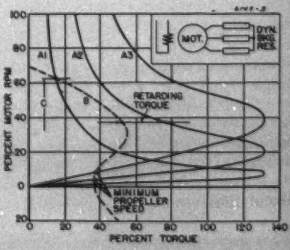

Figure 3. Curves showing dynamic braking torque as a function of motor speed for different values of braking resistance

A—Dynamic braking torque
*A*1—Low dynamic braking resistance
*A*2—Medium dynamic braking resistance
*A*3—High dynamic braking resistance
B—Propeller torque, vessel moving at full speed ahead

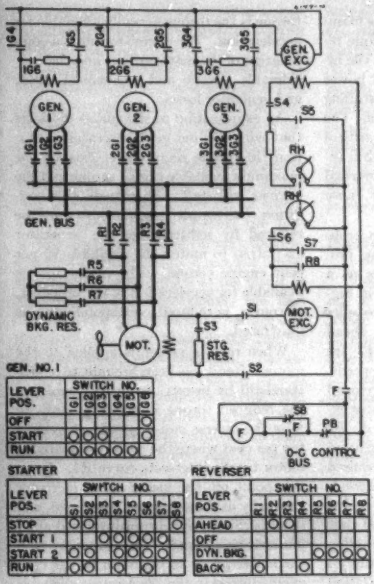

Figure 4. Simplified schematic control diagram for synchronous motor propulsion drive

2. The starter lever and the reverser lever are interlocked to prevent moving the starter lever from the "stop" position, unless the reverser lever is in the "ahead" or the "back" position. Inversely, the reverser lever cannot be moved unless the starter lever is in the "stop" position. Since, in this case, the speed lever must be in the slow speed position, it follows that the reversing contactors cannot be operated unless the generator speed is a minimum and the generator field is de-energized. The operating duty of the contactors, therefore, is considerably lightened.

A speed control transmitter is connected to the speed lever for the purpose of controlling the speed of the engines and, consequently, of the motor over the speed range. Exciter rheostats, required for reduction of generator and motor excitation at reduced speeds, also are coupled to the lever.

Motor Starting

The generators, which will be used for propulsion, are connected to the generator bus by placing the generator levers in the "run" position while the engines are running at idling speed. The generator field switches (1*G*4 and 1*G*5 for generator number one) close and connect the fields to the exciter, which, however, is de-energized since the starter lever is in the "stop" position and switch *S*4 is open. The generators, therefore, will not be synchronized but will run at approximately equal speeds determined by the master speed control transmitter.

As the next step, the reverser lever is moved to the "ahead" position, thereby closing contactors *R*2 and *R*3 and connecting the motor armature to the generator bus. Although motor field switches *S*1 and *S*2 are closed, the motor field remains de-energized since exciter field switches *S*6, *S*7, and *R*8 are open.

Actual starting of the motor takes place when the starting lever is moved to the "start 1" position. Motor field switches *S*1 and *S*2 open and the starting resistor is connected in the field circuit by the closing of switch *S*3. Switch *S*7 closes and applies maximum excitation to the motor exciter in preparation for the motor synchronizing. Simultaneously, the generator fields become overexcited since switches *S*4 and *S*5 close. Although there may be a considerable difference in the speed of the Diesel engines, the synchronizing torque resulting from the overexcitation is sufficient to pull the generators into step and cause synchronization. Following this, the motor starts up as a squirrel-cage induction motor and accelerates gradually to near synchronous speed.

When the motor approaches synchronous speed, the main motor current drops sharply from an almost constant high value during the accelerating period and thereby furnishes an indication that the motor may be synchronized. At this point, the starter lever is moved to the "start 2" position. Switches *S*1 and *S*2 close and connect the motor field to the previously excited motor exciter. Switch *S*3 opens and interrupts the circuit to the starting resistor. As a result the motor becomes energized and begins operating as a synchronous motor. After a few seconds hesitation the starter lever is moved to the "run" position. Switches *S*5 and *S*7 open and reduce motor and generator excitation to normal. The motor speed now may be adjusted to any desired value by means of the speed lever which controls the engine speed control master transmitter.

Discussion of Motor Starting Sequence

The starting sequence, outlined above is unorthodox and probably will be questioned. When first confronted with the problem it would seem more logical first to synchronize and overexcite the generators, connected to the generator bus, and then to start the motor by connecting it to the energized bus. This method is not satisfactory, however, for reasons as outlined as follows.

Before starting the motor, the engines run unloaded at a speed only slightly higher than their minimum stable speed, and the amount of fuel oil, admitted to the engines by the governors, is very low. When connecting the motor to the overexcited generator bus, there will be a se-

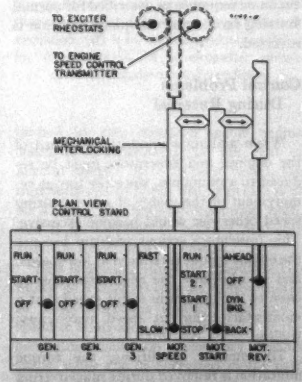

Figure 5. Diagram of lever operating stand with mechanical interlocking

vere and practically instantaneous increase in the generator loading and a corresponding rapid reduction in engine speed. The governors, consequently, will function to increase the amount of fuel oil and the engine torque, but this action is not instantaneous. During the time required to increase the engine torque sufficiently to equal the generator torque, the engine speed frequently will drop below the stable speed and stalling results.

However, when the generators are energized after the motor is connected to the generator bus, the loading increases gradually because of the time constants of exciter and generator fields. The response of the governors is sufficiently fast to follow the load increase, and there is no appreciable reduction in engine speed, and stalling of the engines is prevented.

Motor Reversal

To reverse the propulsion motor when the vessel is making considerable headway, generators and motor first must be de-energized by moving the speed lever to the "slow" position and the starter lever to the "stop" position. The motor now will idle at approximately 70 per cent of normal speed, but is brought quickly to practically standstill by placing the reverser lever in the "dynamic braking" position. Contactors *R5*, *R6*, and *R7* close and connect the braking resistor to the motor terminals. At the same time, switch *R8* closes and applies maximum excitation to the motor field.

As soon as the motor stops, the reverser lever is moved to the "back" position and the starter lever is moved successively to the "start 1," the "start 2," and finally to the run position. The motor starts up in the same sequence as described for normal starting except that the phase rotation is reversed.

Control Problems During Reversal

When making a reversal, the speed of the engines and generators must be reduced to a minimum, since the torque requirement of the motor at synchronizing speed otherwise would become excessive. This presents a serious problem because the engine torque is reduced at low speeds, and also because the engine operates so close to the minimum stable speed that a momentary drop in speed may cause stalling.

To improve conditions, the torque limitation is removed during maneuvering by energizing solenoids on the governors. This will raise the engine torque to 85 per cent or more of normal which can be maintained for short periods. The torque requirement, however, exceeds even the increased engine torque during full power reversals (crash stop) and causes stalling unless special precautions are taken. The condition becomes especially critical where a reversal is attempted with a reduced number of engines. Even normal starting from standstill then may cause stalling.

To obtain a clear picture of the problems involved, curves representing propeller, motor, and engine torques as a function of motor speed are shown in Figure 6. Curve *A1* represents the propeller torque when the vessel is moving ahead at full power speed. *A2* and *A3* are similar curves for reduced ship speeds. Curve *B1* represents the torque developed by the motor at 250 per cent generator excitation and 30 per cent engine speed. *B2* and *B3* are similar curves for reduced generator excitation. The torque required by the engines to produce the corresponding motor torque is represented by curves *C1*, *C2*, and *C3*. It should be noted that the motor torque, as shown, is a function only of the electrical characteristics of motor and generators and has no relation to the propeller torque requirements. The difference between motor and propeller torque is the torque actually available for acceleration. The engine torque is a combination of the motor torque and the considerable electric and mechanical motor and generator losses.

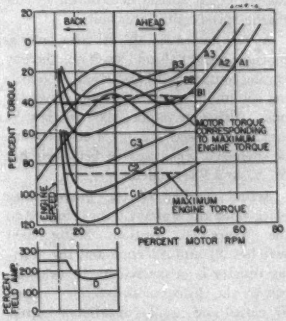

Figure 6. Curves showing propeller, motor, and engine torque as a function of motor speed during reversals

A—Propeller torque
A1—100 per cent ship speed
A2— 85 per cent ship speed
A3— 70 per cent ship speed
B—Propulsion motor torque
B1—250 per cent generator excitation
B2—200 per cent generator excitation
B3—150 per cent generator excitation
C—Engine torques corresponding to above motor torques
D—Generator field current required to maintain maximum engine torque

An examination of the curves discloses that with 250 per cent generator excitation the torque requirement exceeds the maximum available engine torque and the engines will stall. To remedy this condition, the torque requirements must be reduced by reduction of the generator excitation to match the available 85 per cent engine torque. The motor torque available for acceleration of the propeller, of course, is reduced correspondingly, as illustrated.

When reverse power is applied to the motor, after it has been brought to nearly standstill by means of dynamic braking, the reduced torque is sufficient only to raise the reverse motor speed to less than ten per cent where the curve for available motor torque intersects curve *A1*. From this point on, the motor speed increases gradually as the ship speed is reduced, and reaches close to synchronizing speed at 70 per cent ship speed. The generator field current required to maintain 85 per cent engine torque in the accelerating period is represented by curve *D*.

The vessel slows down surprisingly fast as a result of the combined braking effect of hull friction and the reverse propeller thrust, and the time required to accelerate the motor to synchronizing speed is not excessive. The head reach of a vessel with this type of drive compares favorably with the value obtained for similar vessels with d-c drives.

Automatic Torque Control

Satisfactory operation during maneuvering to prevent engine stalling requires automatic control of the generator field current. The current must be maintained at the highest value possible without causing reduction of the engine speed below a permissible minimum value.

A suitable control to meet this requirement is illustrated in the schematic diagram, Figure 7. A small permanent magnet d-c pilot generator *PG* is driven by a 3-phase induction motor, connected to the generator bus through a step-down transformer. The pilot generator voltage is a measure of the main generator frequency and, consequently, of the engine speed. Also coupled to the motor is a regulating exciter *RE* provided with a self-exciting field and a separate control field. A resistor in the self-exciting field circuit is adjusted so that the generator voltage is zero when the control field current is zero, but

will build up to a high value when a very low current is passed through the control field.

The pilot generator is connected in series opposition to a bias voltage across part of a resistor energized from the control bus, and the voltage difference is applied to the control field. The bias voltage is adjusted to equal the pilot generator voltage when the engine speed is 30 per cent of normal. At higher engine speed, the generator voltage exceeds the bias voltage, but current flow through the control field is prevented by a rectifier block. If the engine speed drops as the result of excessive torque requirement, the bias voltage exceeds the generator voltage and a current will flow through the control field in a direction as indicated. The resulting exciter voltage bucks the control bus voltage in the generator exciter field circuit and reduces the field current. This causes a corresponding reduction in main generator excitation and engine torque

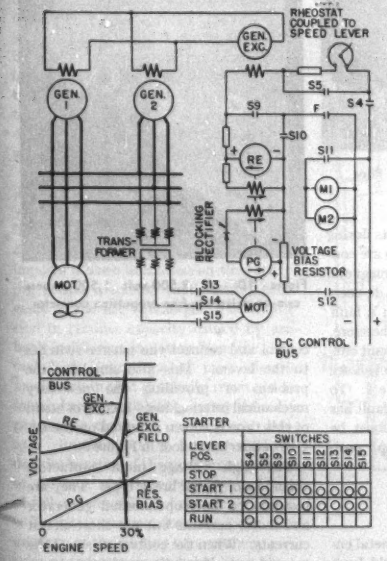

Figure 7. Schematic diagram of automatic engine torque regulation

RE—Regulating exciter
PG—Permanent field pilot generator
M1, *M2*—Engine governor solenoids

until stability is regained. The functioning of the torque regulating equipment is illustrated in Figure 7 by a series of curves showing the relative values of the excitation and control voltages as the engine speed decreases.

Torque control is required only until the motor is synchronized, and the regulating equipment is disconnected when the starter lever is moved to the "run" position by the opening of switches *S*10 to *S*15. The de-energized rototrol is bypassed by switch *S*9. The governor solenoids *M*1 and *M*2, which serve to increase the engine torque during the maneuvering period, are de-energized and normal governor function restored by the opening of switch *S*11 when the starter lever is moved to the "run" position.

Paralleling of Generators

When, during normal operation with one or more generators in service, it becomes necessary to increase the power output by connecting an additional generator to the bus, the first step is to start the associated engine and adjust its speed to approximately the same speed as the engines in service by connecting the governor actuator to the master speed control transmitter. The next step is to move the generator lever to the "start" position, thereby connecting the generator armature to the bus, while the de-energized generator field is connected to a field resistor (see Figure 4). The generator as a consequence, will run as a squirrel cage induction motor and will be forced into near synchronism with the other generators. When, as the third step, the generator lever is moved to the "run" position, the generator becomes energized and pulls into step.

To make possible this simple method of synchronizing, the same consideration must be given to the design of damper winding and field resistor for the generators as for the propulsion motor. With correct design, the synchronizing is very positive and it actually is possible, as has been demonstrated, to start an engine from standstill. If the engine starting lever previously has been placed in the "run" position, the engine will start automatically and begin to deliver power simply by advancing the generator lever to the "start" and then to the "run" position.

Operation at Subsynchronous Speeds

The minimum propeller speed possible with synchronous motor operation is limited by the minimum stable engine speed to approximately 30 per cent of normal speed. On a 20-knot vessel, the minimum steady speed will be in excess of six knots. This speed is somewhat high, and it is desirable to operate at lower speed on some classes of vessels.

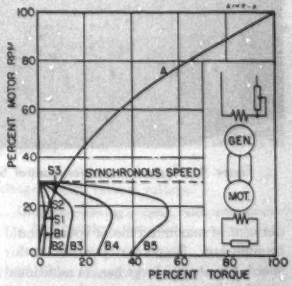

Figure 8. Operation of propulsion motor at subsynchronous speeds

Curves *B*1 to *B*5 show motor torque as a function of speed for different values of generator excitation. *B*1 is for minimum excitation, *B*5 is for overexcitation, *A* is propeller torque curve for steady running condition

This is accomplished by operating the motor as a squirrel cage induction motor at subsynchronous speed. The motor speed is controlled by adjustment of the generator excitation below its normal value, while the de-energized motor field is connected to the starting resistor.

Motor torque curves for several values

of generator excitation are shown in Figure 8. The intersections between these curves and the propeller torque curve give the values of the corresponding motor speeds for steady running. To prevent overheating of motor and generators as a result of high magnetizing and damper winding losses, the generator excitation must be reduced considerably below normal value for continuous operation. Operation at speeds between the minimum synchronous speed and 70 per cent of this value, therefore, is not possible. One speed point at approximately 50 per cent of minimum synchronous speed or 15 per cent of maximum motor speed should be sufficient. To permit operation at this speed, the starter lever has an additional position between "stop" and "start 1" positions, in which a field resistor is inserted in the generator exciter field circuit. For satisfactory operation at least 50 per cent of the generators must be in service.

Protection

The power requirement of a propulsion motor is a function of the propeller speed for any given installation with minor changes caused by the condition of the hull. The motors are designed to supply the necessary torque for the maximum propeller speed and, consequently, cannot be overloaded as long as this speed is not exceeded. The Diesel engines are designed to supply the rated generator output within a narrow margin, thereby precluding overloading of the generators.

Serious overloading of an electric propulsion plant, therefore, is not possible, and, since the equipment is under practically constant supervision when the vessel is under way, normal overload protection is not provided. It is only necessary to protect the main circuits against open circuits and short circuits which occur more frequently than on land installation because of the severe operating conditions.

Phase balance relays in each generator circuit are provided as a protection against this type of fault. The relays trip on a phase unbalance caused by short circuits or open circuits, but are insensitive to the high currents in the circuits during maneuvering. The relay contacts are connected in the coil circuit of a magnetic field contactor and will open and de-energize motor and generators when a fault occurs. The main contactors, therefore, are not required to open short-circuit currents. The contact *PB* of a phase balance relay is shown in diagram, Figure 4. To reset the field contactor after the fault has been cleared, the starter lever must be moved momentarily to the "stop" position when switch *S8* closes.

Design of Control Boards

The control boards are of the metal enclosed dead front type and should have separate compartments for high and low voltage apparatus if space permits. In accordance with standard marine practice, the main and field contactors are usually of the manually operated type for the sake of reliability. Pneumatically or magnetically operated contactors, however, may be more suitable in many instances, especially on large installations since this permits mounting of switch units in convenient locations remote from the main control station. More positive operation is also possible than with manual switching.

Manual contactors usually are operated by cam shafts, connected mechanically to the operating levers. On installations with pneumatically or magnetically operated contactors, master switches are provided for remote control of the contactors. It may be found desirable to retain the lever operating stand also for this type of control and connect the master switches to the levers. This also simplifies the problem of providing the necessary mechanical interlocking. A control board of this type is shown mounted on the engine builder's test floor in Figure 9.

The high voltage main contactors should be of the air break type. They are required to interrupt normal generator and motor currents but not short-circuit currents. When the contactors are of the manual type, it may be necessary to provide trip-free features on the generator contactors to permit remote tripping from the engine gauge boards of associated contactors in case of engine failure. A typical 2,500-volt 1,500-ampere cam-operated trip-free type contactor is shown in Figure 10.

Figure 9. Typical propulsion control board mounted on engine builder's test floor

Figure 10. A 2,500-volt 1,500-ampere cam-operated trip-free propulsion contactor

Rectifier Capacity

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THE LOAD CAPACITY of mercury arc rectifiers must be known in order to utilize them to fullest extent and best advantage. Knowledge of the factors affecting rectifier capacity and the relations between them has increased so that it is now possible to specify the rectifier capacity in definite terms.

Mercury arc rectifier tubes (or tanks) are manufactured only in a limited number of types and sizes. A large variety of rectifier units of different ratings and characteristics may be made up from combinations of one or more similar tubes. Information regarding the capacity and characteristics of each tube (or tank) is essential to the design and application of such mercury arc power converters. It is the purpose of this paper to describe the load-time and volt-ampere characteristics of typical mercury arc tubes of the ignitron type and discuss the relations between these characteristics and the factors affecting them. The control and other characteristics of mercury arc tubes will be treated in a companion paper.[1]

The load carrying ability of a mercury pool tube may be limited by arc-back, voltage surges, loss of control, structural failure, or other action. Of these causes, arc-back is generally determining as it imposes a basic limitation on the rectifying action involving fundamental processes in the arc discharge. The limitation in rectifier capacity caused by arc-back is different in nature from the thermal load limitations of most electric machinery in that it usually results in an impairment in reliability, rather than any permanent electrical or structural damage. Furthermore, it is somewhat indefinite because of the random occurrence of arc-back and the complexity and lack of full understanding of the arc processes.

Temperature rise does not provide a measure of the loading on a mercury pool tube or indicate its probable life. However, the operating temperature of the tube does affect its capacity, as it controls the mercury vapor pressure and establishes conditions for the arc discharge. Thermal limitations of essential components, such as seals, studs, grids, also may affect rectifier capacity, although such limitations are usually readily diagnosed and easily surmounted.

As with most electric apparatus, time is an important factor in rectifier capacity, since the short time capabilities are different from those for continuous operation at a steady sustained load. The time required for a mercury pool tube to reach final temperatures is usually short because of the low thermal capacity of its parts. Furthermore, the time required to establish conditions favorable to the occurrence of arc-back involves all the factors affecting the arc action, of which temperature is but one. For these reasons the relation between magnitude and duration of the limiting load of rectifier tubes differs materially from that for other types of conversion equipment.

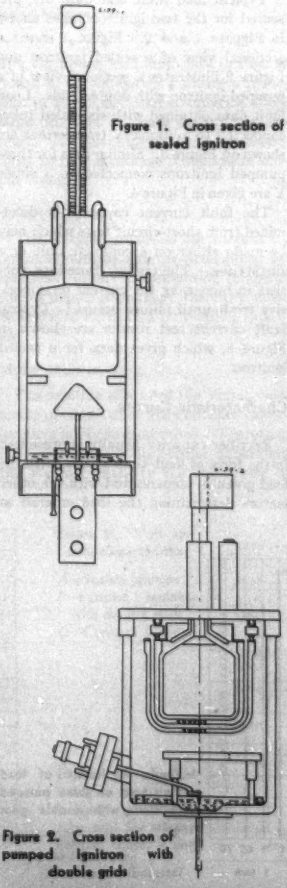

Figure 1. Cross section of sealed ignitron

Figure 2. Cross section of pumped ignitron with double grids

Definition of Loading

The loading on a rectifying device may be described in terms of the magnitude and wave form of the current and voltage impressed upon it during a cycle. The loading is the sum of the effects of both separate and concurrent action of current and voltage. Inasmuch as the rectifying device performs only a switching action, the magnitude and wave form of the current and voltage depend almost entirely on the power circuit. The loading imposed upon the rectifying device by the circuit is termed the circuit duty.[2]

The capacity of a rectifying device may be expressed in terms of the circuit duty that it is capable of withstanding without failure. Some of the more important elements of the circuit duty are as follows:

1. Voltage—peak inverse and forward voltage; initial inverse voltage.
2. Current—average, peak, and rms current; final commutation rate.
3. Frequency (of a-c system).
4. Duration of loading.

Circuits differ in the amount of duty they impose upon the rectifying device because of differences in magnitude and form of the current and voltage waves. Also, the various elements of circuit duty have different weightings relative to the over-all loading on the rectifier. Since the effects of the various elements of circuit duty upon rectifier capacity are to a large degree mutually dependent, it is necessary to state the rectifier capacity for several different types of circuit duty in order to fully describe its capabilities.

It is often more convenient to state the rectifier capacity in terms of factors more directly related to the circuit constants and performance characteristics than in the elements of circuit duty. Some of these factors are:

1. Mode of operation (number of rectifier phases).
2. Direct voltage.
3. Direct current.
4. Amount of phase control.
5. Reactance.

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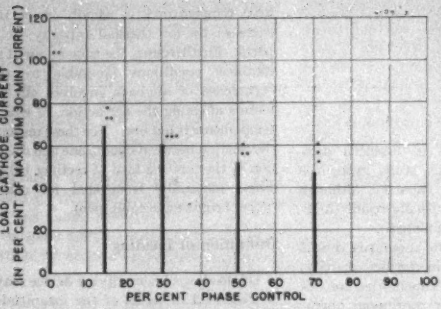

Figure 3. Results of 30-minute load limit tests on six sealed ignitrons

Dots indicate arc-back

A full statement of rectifier capacity also must include the capabilities and limitations under loadings of one cycle duration, that is, the fault current capacity. This capacity is defined as the crest value of current which the rectifying element can carry without incurring voltage surges during the conduction period or arc-back in the succeeding inverse period.

Determination of Capacity

The design of mercury arc rectifiers is based to a large degree on experimental data obtained from tests. As a consequence, each new design requires extensive tests to check its adequacy and determine its capabilities.

Rectifier capacity is determined from load test which consist in operating the rectifier under loads of increasing severity until failure occurs.

Load tests may be made on either a complete unit with a full complement of tubes, or on a section with only enough tubes to obtain the desired circuit action. Accelerated load tests have been termed load limit tests, and the procedure for making them has been described in a previous paper.[3]

Typical load limit test data are presented for the two ignitron tubes shown in Figures 1 and 2. Figure 1 shows a sectional view of a sealed ignitron and Figure 2 illustrates a sectional view of a pumped ignitron with double grids. Load limit data obtained with six sealed tubes connected to a double-Y transformer are shown on Figure 3. Similar data for three pumped ignitrons connected to a single Y are given in Figure 4.

The fault current capacity is determined from short-circuit tests which may be made either on a complete unit or a single tube. The testing procedure consists in increasing the current on successive trials until failure occurs.[3] Typical fault current test results are shown in Figure 5, which gives data for a sealed ignitron.

Characteristic Curves

Rectifier capacity usually is presented in the form of load–time curves, with the load given in amperes and with the other factors determining the load entered as parameters. These curves may be drawn directly from the data obtained on load limit tests, as the usual procedure is to make tests at a given voltage and vary loading by changing the load current.

Load–time curves for the sealed ignitron are shown in Figure 6 and for the pumped ignitron on Figure 7. The load–time curves are plotted most conveniently on a semilogarithmic scale because of the short thermal time constant of the tube and the short duration of the accelerated load limit tests. Values for the 30-minute and 2-hour points on the curves are obtained from the 30-minute load limit tests,* which are made by increasing the load by a fixed increment every half hour. The 30-minute point is then the highest load which was carried successfully without arc-back, and the 2-hour point is taken as the load three increments below. The load–time curves are usually almost straight lines, so values for times longer than two hours may be estimated by extrapolation. Final thermal conditions usually are attained in less than four hours, and experience has shown that the continuous capacity of rectifier tubes does not differ greatly from their 4-hour capabilities. The load capabilities indicated by these curves are limited by arc-back. Where structural features are limiting, different load time relations may be obtained.

A load–time curve may be drawn for each condition of rectifier operation, such as voltage, phase control, reactance, temperature, mode of operation. A complete statement of rectifier capacity therefore requires several families of load–time curves. However, it is frequently desirable to indicate the effect of the other load factors directly. The relationships between some of these factors and rectifier capacity follow.

Voltage

A given mercury pool tube may be operated over a wide voltage range. The load capacity in amperes decreases as the

* Previously designated continuous load limit tests.

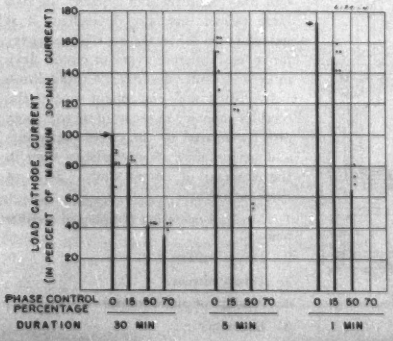

Figure 4. Results of load limit tests on three pumped ignitrons with double grids

Arrows indicate limit of testing facilities

Dots indicate arc-back

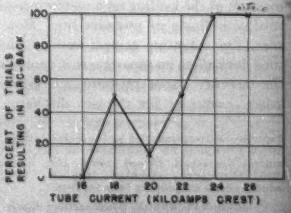

Figure 5. Fault current capacity of sealed ignitron

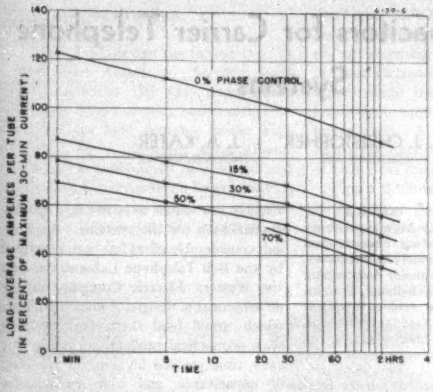

Figure 6. Load–time characteristics of a sealed ignitron

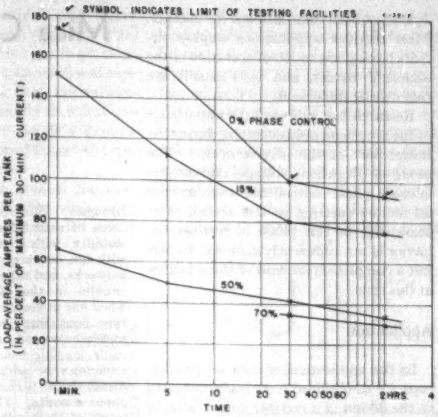

Figure 7. Load–time characteristics of a pumped ignitron with double grids

operating voltage is raised. However, the reduction in current capacity is usually less than the increase in voltage, in that the kilowatt capacity of a rectifier is generally increased as the operating voltage is raised.

These characteristics are shown best by plotting the rectifier capacity as a volt ampere relationship on a logarithmic scale, as in Figure 8. The volt ampere characteristics of both the sealed ignitron and the pumped ignitron are shown. Both have a greater slope than the constant kilowatt curve, indicating an increase in kilowatt capacity as the voltage is raised. Adequate data to establish the volt ampere characteristics as fully as might be desired are not available.

Phase Control

The effect of phase control upon the capacity of certain types of tubes is shown directly by the load limit data in Figures 3 and 4. These curves indicate a reduction in 30-minute current capacity when large amounts of phase control are applied. The percentage phase control is defined as the percentage reduction in output voltage.

Temperature

The rectifier usually is operated at its optimum temperature as determined by load limit tests. The operating temperature or temperature range, therefore, must be included with data on rectifier capacity.

Mode of Operation

The relative effects of the various elements of circuit duty upon rectifier capacity have not been established. Therefore, it is not possible to predict accurately the rectifier capacity for one mode of

Table I. List of Typical Tube Ratings

Tube Type and Description	Class of Service	Rated Output* Kilowatts	Volts	Amperes
Type A ignitron	Industrial	150	250	600
		200	600	333
Type B ignitron	Industrial	300	250	1,200
		500	600	833
Type C ignitron	Industrial	8,100	9,000	900
Type D ignitron	Industrial	600	250	2,400
		1,000	600	1,666
Type E ignitron	Industrial	1,000	250	4,000
		2,000	900	3,330
Type F ignitron	Railway (Classes II and III)	4,000	3,000	1,333
Type G ignitron	Industrial	1,500	250	6,000
		3,000	600	5,000

* Rating of six tubes in double-Y circuit.

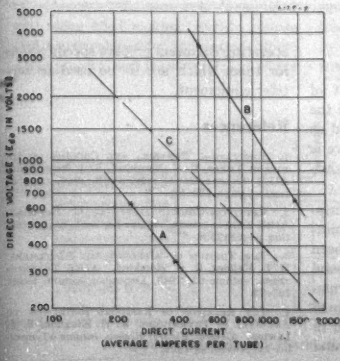

Figure 8. Volt ampere characteristics

A—Sealed ignitron
B—Pumped ignitron with double grids
C—Constant kilowatt

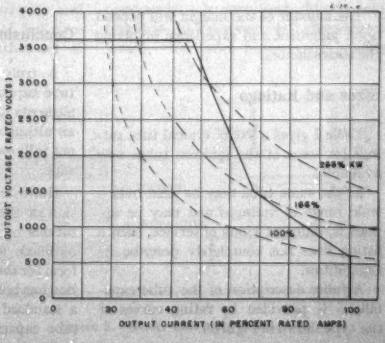

Figure 9. Typical rating curve for pumped ignitron—6-tube unit for railway service, classes II and III

operation from data obtained for another. Most rectifier applications employ circuits having the mode of operation of the double-Y circuit, and tests usually are taken using this circuit.

Research has indicated the importance of the arc phenomena occurring during the initial part of the inverse cycle.[4] The mode of operation, voltage, current, reactance, phase control, and frequency are all factors entering in this action. Our knowledge of this phase of rectifier behavior is not sufficiently complete to permit a complete treatment of these factors at this time.

Application

In the application of data on rectifier capacity as obtained from load limit tests to the design of a rectifier unit a margin must be allowed between the rated or anticipated load and the capacity indicated by tests. This tolerance must be provided to cover the following contingencies:

1. Differences between normal and accelerated loading. It must be recognized that load limit tests are short time or accelerated tests and do not duplicate accurately all the effects of sustained operation in service.

2. Differences in circuit duty. Where load limit tests are made on a set of three tubes, the circuit duty may be less than that incurred on a complete rectifier circuit.

3. Transformer unbalance. Unbalanced transformer reactances may cause unequal tube currents. Transformers usually are designed to permit an unbalance in neutral currents not exceeding five per cent. (The per cent unbalance is defined as the ratio of the difference between actual and rated neutral current to rated neutral current.)

4. Service requirements. The requirements of various applications differ with respect to reliability, depending upon the economic penalties or operational hazards incurred by the occurrence of arc-back.

The amount of the margin will depend upon judgment and experience involving the above factors.

Sizes and Ratings

Table I gives a list of typical tube ratings for some of the ignitron tubes now available.

As the same tube may be used over a wide range of voltages and may be applied to different kinds of service, such a listing does not completely describe its capabilities.

A fuller description of the tube capabilities is provided by rating curves of the type shown in Figure 9.

Mica Capacitors for Carrier Telephone Systems

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Synopsis: Silvered mica capacitors, because of their inherently high capacitance stability with temperature changes and with age, now are used widely in oscillators, networks, and other frequency determining circuits in the Bell Telephone System. Their use in place of the previous dry stack type, consisting of alternate layers of mica and foil clamped under high pressures, has made possible considerable manufacturing economies in addition to improving the transmission performance of carrier telephone circuits. These economies are the result of their relatively simple unit construction and the ease of adjustment to the very close capacitance tolerance required.

PRESENT DAY carrier telephone systems are placing special demands on capacitors used in frequency determining and frequency sensitive circuits with particular emphasis on initial precision, low a-c losses, and high capacitance stability with temperature and time. In these systems mica capacitors are used in the oscillating circuits and also are used extensively in the electric filters employed to segregate the numerous and closely spaced carrier frequency channels. For these applications the transmission potentials applied to capacitors are quite low and in general do not exceed a few volts. These capacitors, however, must meet very stringent requirements for capacitance tolerance at the time of manufacture, and any subsequent changes in capacitance caused by temperature changes and age must be held to extremely low values to insure high quality transmission for the systems. As a result considerable effort has been expended by the Bell Telephone Laboratories and the Western Electric Company in the development of designs of mica capacitors which would lend themselves to large scale economical production, and at the same time provide high initial precision of capacitance and high capacitance stability over long periods of time under service operating conditions. To meet these exacting demands, mica capacitors having sprayed silver electrodes intimately bonded to the mica laminations were developed and introduced several years ago into the Bell System in quantities to replace the former less stable and more expensive designs.

As a matter of historical interest, silvered mica capacitors were manufactured by the Western Electric Company and used in the Bell System more than 40 years ago as capacitor standards in laboratory measurement work. These silvered mica capacitors were made by the relatively expensive method of chemical deposition of the silver on the mica.

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Conclusions

A truly comprehensive statement of tube capabilities directly in terms of the elements of circuit duty is recognized as an ultimate objective. This objective is not fully possible with our present knowledge.

However, a procedure for the description of the load capabilities and limitations of mercury pool tubes has been outlined, and a convenient and useful form for the presentation of such information has been developed. The adoption of a standard form for the specification of tube capacity will help application and operating engineers prepare specifications for tubes which are to be used in rectifier equipment.

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Physical Construction

Figure 1 illustrates the former type of construction known as the dry stack mica capacitor. In this construction alternate layers of mica and tinned copper foil are held together under high pressure by a clamping arrangement. The unit is maintained in a sealed and nonimpregnated condition by potting in a metal container in a viscous asphaltic compound which does not penetrate the

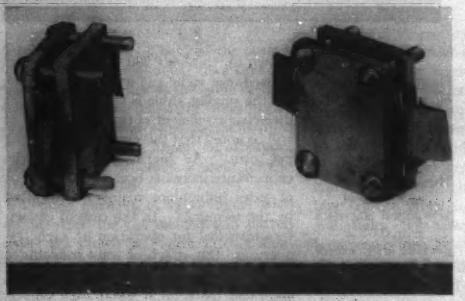


Figure 1. Dry stack mica capacitor units

unit appreciably even in its fluid state.

Two distinct types of silvered mica capacitors were developed for general use in carrier telephone systems. One type known as the potted design was provided for applications where the highest initial precision and highest capacitance stability are required for services involving a limited range in operating temperature usually from about 60 to 100 degrees Fahrenheit. These capacitors are provided in several sizes of extruded nonmagnetic containers and provide for any desired capacitance value up to 0.4 microfarad. The other type is provided with mica filled molded bakelite casings and was developed for applications where small physical size is essential, but where the higher initial precision and higher capacitance stability of the potted types are not required. This type is provided in three physical sizes to cover a capacitance range from a few micromicrofarads up to approximately 20,000 micromicrofarads. A more detailed description of the construction of these two types of capacitors will be given.

Figure 2 shows the area of the mica lamination covered by the silver electrode. This area is coated with a suitable silver solution by spraying after masking the areas required for margins. The laminations then are fired at a high temperature for a short period to form a tight bond between the silver and mica. The laminations then are stacked, as shown in Figure 3, with a continuous strip of lead foil *F* interleaved between silvered surfaces so that one set of silver electrodes is joined electrically together and to the foil. Another strip of foil likewise is connected to the other set of

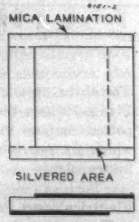


Figure 2. Silvered mica lamination

electrodes on the opposite faces of the laminations. The purpose of looping-in the foil instead of using separately laid-in strips of foil is to permit a continuous indication of capacitance during stacking by means of a precise capacitance meter connected to the ends of the foil. Adjustment for capacitance first is made roughly by adding a sufficient number of laminations so that the measured value is somewhat larger than required. Terminals *T* then are crimped tightly over the ends of the foil to the mica stack to complete the unit assembly. The assembled unit of the potted capacitor after drying and coating with a thin layer of mineral wax, then is finally adjusted to close tolerance by removing the silver coating as required from the upper exposed surface shown in Figure 3. This has made possible the provision of capacitors meeting commercial tolerances of $\pm$(0.2%+2 micromicrofarads) after being potted in wax in metallic containers. The molded case capacitor units are treated and adjusted in the same manner except that the wax dipping is omitted and the final adjustment prior to molding is accomplished by removing silver coating from the top lamination in a dry condition. Because of less predictable capacitance shift caused by molding the best commercial tolerance for molded capacitors is $\pm$ (0.5 per cent + 1 micromicrofarad). To insure high over-all quality

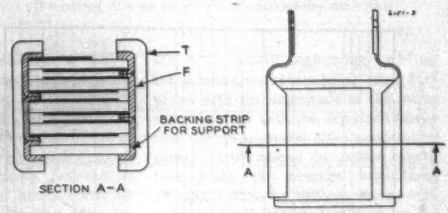


Figure 3. Silvered mica unit construction

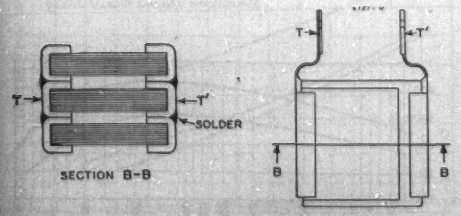


Figure 4. Multiple unit construction

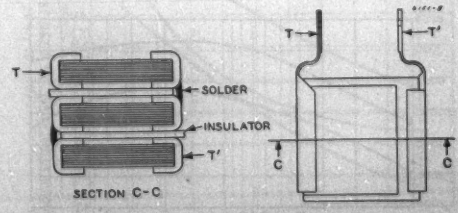


Figure 5. Series unit construction

Figure 6. Molded silvered mica capacitors in current production

Figure 7 (right). Potted silvered mica capacitors in current production

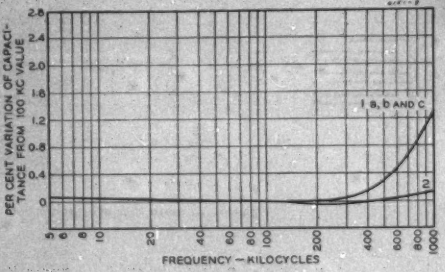


Figure 8. Variation of capacitance with frequency

1a = potted silvered mica, 0.01 μf
1b = molded silvered mica, 0.01 μf
1c = potted dry stack mica, 0.01 μf
2 = same as 1, except 0.001 μf

and performance all assembly operations are carried out in air-conditioned space where the relative humidity is maintained under 40 per cent at 75 degrees Fahrenheit.

Two or more of these unit assemblies are joined together mechanically and electrically to provide for the higher capacitances for the potted designs, as shown by Figure 4. For applications, such as line filters where high surge voltages may be encountered, several sections are connected in series, as shown in Figure 5.

In the case of the molded design, only single units are employed in the assembly because of the high molding pressures. The three sizes are shown in Figure 6. Figure 7 shows the five sizes of the wax potted designs in extruded containers which are provided for use in the Bell System plant.

Electrical and Performance Characteristics

The following discussion will deal with the more important electrical characteristics of dry stack and silvered mica types of capacitors and will cover data obtained on commercially made samples considered to be typical for these two types. Figure 8 shows the variation of capacitance with frequency over a frequency range of 5 to 1,000 kc for potted dry stack, potted silvered mica, and molded silvered mica capacitors of 0.01 and 0.001 microfarad capacitance. The capacitance change shown up to about 200 kc for the larger capacitance value and up to about 400 kc for the smaller value is dependent on the dielectric coefficient of the mica itself. It will be noted that this change is within 0.1 per cent. At higher frequencies the capacitance increases because of the effect of series inductance mainly contributed by the terminals. In the case of capacitors intended for operation at high frequencies, the effect of this inductance must be taken into account and proper allowance made for it where high capacitance precision is required.

Figure 9 shows the change in Q with frequency of 0.026 microfarad dry stack and silvered mica potted capacitors from 1 kc to 100 kc, and Figure 10 shows the change in Q of 0.001 microfarad potted and molded silvered mica capacitors from 5 to 1,000 kc. The average Q of the silvered mica potted design is higher, and the variation of Q with frequency is somewhat less than that of the dry stack design. It is believed that the inherently higher Q of the silvered mica design results from reduced losses caused by the elimination of asphaltic potting compound and elimination of absorbed hydrocarbon material, as well as small traces of water vapor from the surface of the mica by the very high

Figure 9. Variation of Q with frequency for potted silvered and dry stack mica capacitors

1 = silvered mica, 0.026 μf
2 = dry stack mica, 0.026 μf

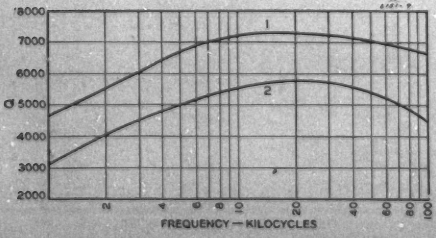
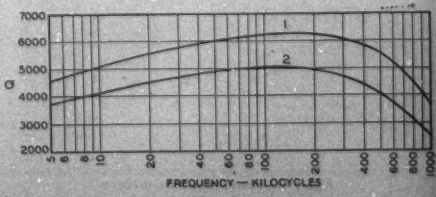


Figure 10. Variation of Q with frequency for potted and molded silvered mica capacitors

1 = potted silvered mica, 0.001 μf
2 = molded silvered mica, 0.001 μf



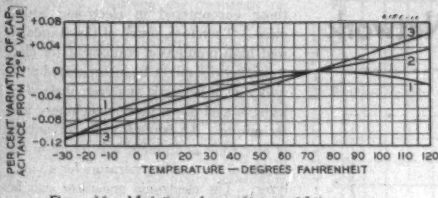


Figure 11. Variation of capacitance with temperature

1 = potted silvered mica, 0.01 μf, 10 kc
2 = molded silvered mica, 0.01 μf, 10 kc
3 = potted dry stack mica, 0.01 μf, 10 kc

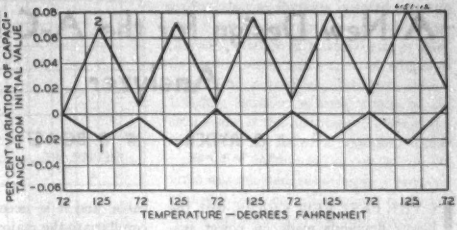


Figure 12. Variation of capacitance with temperature cycling

1 = potted silvered mica 2 = potted dry stack mica

firing temperature. The Q of the potted silvered mica also is higher than that for the molded capacitor of the same capacitance value. The dielectric losses in the phenolic casing and some contamination of the unit from the liberation of vapors during molding probably account for the lower Q of the latter.

Typical changes of capacitance with temperature for the molded and potted types are shown in Figure 11. It illustrates a pronounced difference between the molded and dry stack potted types as compared to the potted silvered mica construction. In the case of the molded and dry stack potted types, the change of capacitance with temperature primarily is caused by changes in the physical dimensions of the unit. These changes are such as to produce a positive temperature coefficient throughout the entire temperature range. In the case of the wax treated and wax potted silvered mica capacitors, the capacitance changes with temperature are caused by changes in the physical dimensions of the unit and also by the effect of the wax, having a high negative temperature coefficient, on the fringing capacitance of the unit. As a result the temperature coefficent is positive up to about 60 degrees and is negative above approximately 80 degrees. Between 60 and 100 degrees, the usual operating temperature range for central office installations, the temperature coefficient is extremely low.

Figure 12 shows the variations in capacitance of a typical potted silvered mica capacitor and also, for comparison, the same characteristic for a typical dry stack potted capacitor with repeated changes in temperature from room temperature to 125 degrees. The drift in capacitance resulting from repeated temperature cycles is caused by such conditions as small permanent displacement of the laminations in the assembly, small changes in the effective separation of the electrodes, and possibly small changes in the effective dielectric constant. Figure 12 illustrates how the drift in capacitance caused by the foregoing conditions, is minimized in the silvered mica capacitors. Data indicate that the potted silvered mica capacitors, also are more uniform from sample to sample in over-all capacitance stability, the extreme variations being one-fourth to one-fifth the magnitude of the variations observed with the dry stack design over the usual central office temperature range. In the case of the molded capacitors, while the average capacitance changes caused by drift as well as temperature coefficient are less than for the dry stack type, their capacitance changes have been found to be approximately double those of the potted silvered mica designs under the same conditons.

Figures 13 and 14 show the third order modulation characteristics for the potted and molded types. This characteristic is a measure of the capacitor's creation of new and unwanted frequencies while transmitting frequencies impressed upon it. In the case of capacitors, the creation of unwanted frequencies is the result of nonlinear effects caused by mechanical vibration and dielectric hysteresis. Un-

Figure 13. Variation of modulation with frequency

1 = potted silvered mica
2 = molded silvered mica
3 = potted dry stack mica

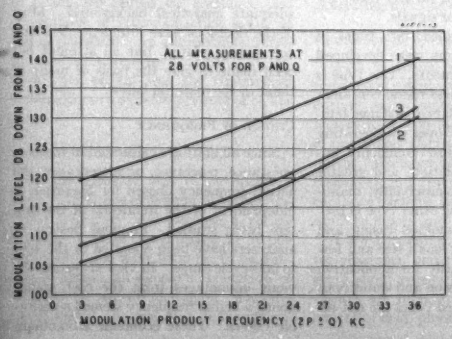
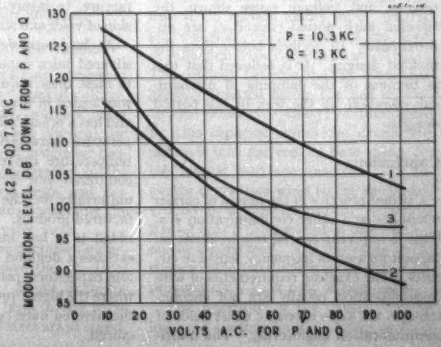


Figure 14. Variation of modulation with applied voltage

1 = potted silvered mica
2 = molded silvered mica
3 = potted dry stack mica



A New Design for the A-C Network Analyzer

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IN THE PAST FEW YEARS, with the heavy demands made on power systems, an increased interest has developed in network analyzers for public utility use. This has resulted in installation of several new analyzers and design or planning of others. In line with this trend, the Iowa State College has been active in developing and constructing an analyzer for use by utilities of the midwest area. Following general educational policy, the work was undertaken as a research project of the Iowa Engineering Experiment Station to determine the feasibility of applying new equipment and new techniques in improving the design of the a-c network analyzer.

In beginning the work, investigations were made which established a major premise, namely, that higher frequencies than those employed in the past could be used profitably. However, if frequencies are carried higher than previously, conventional instruments become inapplicable, and it is necessary to adopt as a corollary to the major premise, that complete electronic instrumentation will be desirable. As an additional advantage for this system, the instrument burden on the network can be reduced to a desirable minimum, and no longer serves as a major design limit on currents, voltages, and impedances employed.

One reason for raising frequency was a desire to draw on the techniques and apparatus common to electronics and radio, to determine if an amalgamation of the power and radio fields might lead to an improved design. Power levels used in network analyzers are approximately

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less these unwanted frequencies are held to very low energy levels as compared to the energy levels of the desired frequencies, in some cases less than one part in ten billion (100 decibels), crosstalk between carrier channels or noise or both seriously may impair high fidelity transmission of carrier telephone systems. It will be observed that over the frequency and voltage range shown, the silvered mica potted capacitors are approximately 15 decibels better than the molded designs. It is believed that this is because of the damping of mechanical vibration by the wax in the potted designs.

Conclusions

Current practice in the design of carrier telephone and other communication systems is imposing special requirements on capacitors used in frequency sensitive circuits. The exacting requirements of wire communication usually are not encountered to the same extent in other fields of communication engineering. The multiplicity of channels on a single pair of conductors, the large number of elements involved in a long circuit, and the constant use of these channels for years without adjustment or replacement of circuit elements impose very stringent requirements on capacitance tolerance at the time of manufacture, and on permissible change in capacitance subsequent to manufacture, to insure high fidelity transmission of voice and similar signals.

As has been described, two types of silvered mica capacitors were developed to meet these requirements. One type is wax sealed in a seamless metal container and has a practically flat capacitance temperature characteristic over the operating temperature range most commonly encountered, low modulation, and greater uniformity in the commercially manufactured product. The other type is provided in a low loss molded casing and satisfies a demand for small size and low loss capacitors, primarily for application where the higher precision and stability of the silvered mica potted types are not required.

those encountered in electronic equipment. Therefore, much of the standardized high production equipment for electronic service might be incorporated profitably in a network analyzer, instead of using scaled down power machinery and techniques. An example of the advantage of electronic equipment was found in the design of electronic generators for an analyzer. The electronic generator can be built with performance improved over that of the conventional induction motor phase shifter type, and at a much reduced cost.

An important economic factor influencing the decision to operate at a higher than normal frequency was the possibility of lowering cost through use of smaller values of inductance and capacity for given values of reactance. A valuable technical advantage which could be realized at a higher frequency was the elimination of iron cores in the inductive reactors, with consequent improvement in constancy of inductance at all current values and freedom from wave form distortion.

It should be understood that while the network analyzer to be described has proved its ability and the correctness of the fundamental design assumptions, it will continue in an experimental state for a considerable period of time. Built as a small pilot model, to prove the design, and to handle only simple problems, the analyzer may be increased in size by the addition of units in the future. Some modifications based on experience may be necessary, and compromises in equipment choice, forced by wartime conditions, may be eliminated in the larger model.

Fundamental Design Features

In the design of an analyzer in a new frequency range, extrapolated far beyond previous experience, many design decisions had to be made with and without adequate analytical background. Most of the decisions were interdependent and not simply related, but an attempt has been made to give the basis of many of them in the material below.

Choice of Frequency

Since all units are calibrated in terms of resistance, reactance, or susceptance, the actual frequency chosen for operation is independent of the frequency of the system being studied. Previous designs of analyzers have been operated in the 400- to 500-cycle range. In view of certain obvious advantages from the cost standpoint, a higher frequency seemed a desirable choice. These economic advantages

are twofold. Raising the frequency reduces the size of inductors and capacitors required for given reactance values, thus reducing the cost. Also, if the frequency is raised sufficiently, the ratings of many parts become those common to the radio industry, and the high production in this industry further reduces the price. Radio industry components are made in a great variety of sizes and are easily obtainable, which are both desirable advantages. While of somewhat variable quality, it is possible to obtain radio parts which are entirely dependable. This can be accomplished by careful selection of the manufacturer and avoidance of parts obviously built down to a price.

The curve shown in Figure 1 illustrates the variation in price of 100 ohms of capacitive reactance at various frequencies. They are list prices for good quality capacitors, and it is assumed that units of the exact required capacitance could be purchased with no paralleling of small units being necessary. It is probable that inductor costs also would show a considerable drop with frequency, although, as inductors are not common items of commerce, comparable prices cannot be obtained. The curve shown in Figure 1 is not meant to apply to capacitors alone, but is intended to give an indication of the trend in both inductor and capacitor costs with frequency.

Based on this reasoning, a tentative selection of the frequency base for the analyzer was made. This selection was subject, of course, to confirmation or change as other design features were checked. The frequency chosen for the Iowa State College a-c network analyzer was 10,000 cycles per second. This represents a major extrapolation of previous experience. Choice of a frequency substantially below 10,000 cycles per second would have made inclusion of iron cores in the inductors a necessity, and choice of a frequency much higher would have led to difficulties caused by reactance and susceptance of interconnecting leads, as will be discussed. An additional factor in the choice of a frequency of exactly 10,000 cycles per second was the commercial availability of a satisfactory source of low cost.

Frequency Source

As the analyzer was to be operated from a small power system of rather unstable frequency and because a rotary machine of small power rating at 10,000 cycles with sine wave form might be difficult to obtain, all-electronic operation of the analyzer was decided upon. This decision meant the use of a temperature-controlled quartz-crystal standard-frequency oscillator, operating at 100,000 cycles per second as the primary frequency source. By occasional checking against standard frequency signals from radio station WWV of the Bureau of Standards in Washington, this oscillator can be maintained within one cycle at 100,000 cycles, an accuracy in frequency of 0.001 per cent. In actual service, without adjustment, the error has never been found greater than five cycles at 100,000 cycles.

With frequency dividing circuits, the 100,000-cycle signal is subdivided by a factor of ten, yielding a 10,000-cycle output of a few volts, with reasonably good wave form, as the primary frequency source for the analyzer. This voltage then is filtered for wave form improvement and applied to amplifier circuits which are used to develop the power needed in the outputs of the equivalent generating stations of the analyzer.

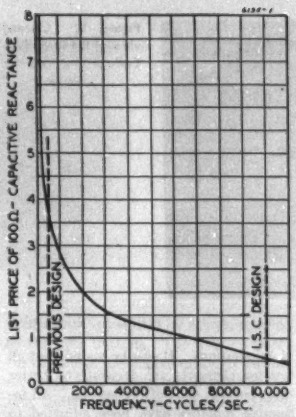

Figure 1. Estimated cost of 100 ohms of capacitive reactance at various frequencies

Choice of *E*, *I*, and *Z* Base Values

With metering limitations somewhat removed in setting base values of voltage, current, and impedance, various other factors to be considered are physical size of units, and electric and magnetic couplings. Also needing consideration are the resistance and reactance drops and susceptance currents in leads connecting the units to busses and transfer jacks.

A low impedance base decreases inductor reactance and reduces the effects of stray shunt capacities. Shunt capacitor ratings are increased, but, in the radio capacitor field, physical sizes are so standardized that an increase in rated capacity over a ten to one range may mean no appreciable change in physical size or cost. Capacitor sizes, and expected effects of shunt lead capacities, indicated that a 100-ohm impedance base would be desirable and it was adopted. To keep electric coupling between circuits within units to a minimum, a voltage of ten volts was selected, resulting in a base current of 0.1 ampere. The power dissipated in the network is so low that small resistors may be used safely without fear of burning out on accidental overloads.

Interconnection of Units

For accurate operation of the analyzer, all leads from units to busses, transfer jacks, and so forth, should introduce negligible resistance, reactance, and susceptance into the circuit. At 10,000 cycles the problem of inductive and capacitive coupling between circuits can be severe unless transposition or shielding is used. Various types and sizes of wire for these lines were investigated with respect to resistance, series reactance, and current taken by the susceptance. Standard tolerances were set up as 0.1 per cent of base values.

Calculations were made on standard types of twisted pair lines used for radio frequency transmission, which indicated that certain types would meet the specifications on resistance and reactance, but might cause larger than desired shunt capacity currents. It was hoped that the twisted pair feature would introduce sufficient transpositions to reduce coupling. A better solution for elimination of inter-circuit coupling was the coaxial cable, and computations indicated that some types would have satisfactorily low circuit values. The complete absence of external field eliminates all circuit coupling, and a $\frac{3}{8}$-inch diameter double conductor (Twinax) coaxial cable was adopted for interconnections. The double conductor and shield feature allows input, output, and common ground leads of a line, load, or other unit to be carried in a single cable. The capacity between the two wires then appears shunted across the line or load circuit elements. The error introduced by this capacity across the circuit elements is 0.25 per cent of base value, for the longest lead encountered. The capacity of the two wires to the shield and ground is negligible, causing a current flow of only 0.075 per cent of base current on the longest lead. The resistance of the chosen cable for the longest length is approximately 0.1 per cent of base value.

The reactance of the chosen Twinax line was another limiting factor and for

Figure 2. General view of the Iowa State College a-c network analyzer

the longest lead is 0.1 per cent of base value. This fact influenced the choice of 10,000 cycles as base frequency. The magnitude of these limiting factors indicates that a cable design with slightly larger conductors would be desirable. Such a cable was not a commercial product and under wartime conditions it was necessary to design around available equipment.

Inductive Reactances

One of the reasons for the choice of 10,000 cycles as base frequency was the possibility of eliminating all iron in the line and load inductors by the use of air core coils. Use of air core coils removes all anxiety as to wave form distortion by the iron, and constancy of inductance at all current values. Lower losses or higher ratios of reactance to resistance also have been achieved than those mentioned for iron core coils in lower frequency network analyzers.

Air core coil designs have been developed for all sizes of reactors used, which give all inductors phase angles of above 88 degrees, and certain much used load inductor values above 89 degrees. All coils are shielded in mutually perpendicular pairs, and the above phase angle measurements are with shielding in place. The resistance component introduced by any coil of a load unit may be considered as two per cent of the rated reactance, and of any coil of a line unit as four per cent of rated value. Each decade of a reactor group is obtained by series switching of 1-, 2-, 3-, and 4-ohm reactors or multiples of these values.

Accuracy

A definite statement of the accuracy to be expected from such a complex mechanism means very little because of additive and subtractive errors introduced by so many circuit elements in cascade, and to usage of meter readings in various types of calculations. It can be stated that all resistor elements are accurate to better than one per cent of the setting. All inductive reactors have been adjusted to within 0.2 per cent and, because of the air core construction, will maintain that accuracy at all current values. Capacitive susceptors have been assembled to match the 0.2 per cent maximum deviation requirement. The metering system has been calibrated from d-c standards by thermocouple transfer units to one-half per cent or better of full scale values for normal loading conditions.

Use of Standard Radio Equipment

It already has been emphasized that the selections for frequency and impedance bases made possible the use of standard high production radio components and coaxial cable. In addition, the radio and telephone industries have developed a line of standardized instrument racks and panels which have advantages in flexibility and availability. These panels are 19 inches wide with heights in multiples of $1\frac{3}{4}$ inches. The racks are 20 inches wide, six feet high, with mounting holes so arranged that panels can be mounted at any point desired. Such an arrangement will permit easy changes in the future if needed. A view of the complete analyzer is shown in Figure 2.

Control Desk

The main control and metering desk, illustrated in Figure 3, was designed in modern style and finished to harmonize with the panel equipment. Its design permits the operator an easy view of the complete analyzer and houses all instrument amplifiers and certain relays.

The desk combines analyzer controls and master instruments on a sloping panel. The angle of the panel was chosen to be comfortable for the operator in either controlling the analyzer or taking data. On the panel, and accessible to the left hand, are the main 60-cycle power controls, lever keys for connecting the instruments to either input or output circuits of any analyzer unit, a watts-vars switch, and a switch to place the desk instruments in operation.

Also operated by the left hand are the push buttons for preselection of relays by which the desk master instruments may be connected in any circuit. By simply pushing buttons corresponding to the number of the unit to be metered, as on an adding machine, the relay circuits are selected. The capacity of the push button system is 999 circuits which, by reason of the input and output relays on each unit, will permit metering at 1,998 distinct points should that number ever be required. All push buttons are mechanically interlocked to prevent metering two circuits at once. By assigning these controls to the left hand, a pencil held in the right hand for taking data or other work need not be dropped during operation.

Figure 3. The main metering and control desk

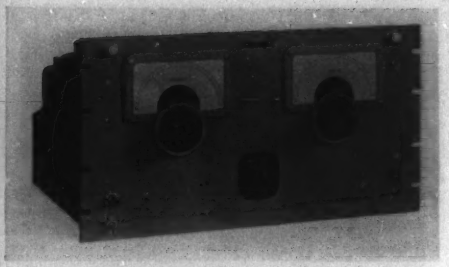

Figure 4. Front panel of a generator unit

The dials are for adjusting voltage and phase angle

The desk instruments are subsurface mounted and internally illuminated with fluorescent lamps, giving a very uniform glareless shadow-free light. The upper and lower rows of instruments are placed at different vertical angles so that an observer of average height will have a line of sight perpendicular to the meter scale for both instrument rows. This materially reduces the fatigue of the operator. Mounted below the instruments are range switches for the ammeter and voltmeter and a reversing switch for the wattmeter. Working in conjunction with the range switches are colored signal lights above the voltmeter, ammeter, and wattmeter, indicating the range multiplier in service at any time.

The instruments used all are operated electronically and comprise a voltmeter, an ammeter, a watt-varmeter, and two phase angle meters. The phase angle meters are at each side in the lower row, the other instruments being placed in the upper row with the wattmeter in the center. Amplifiers for operating these instruments are installed inside the control desk. The voltmeter and ammeter are fairly conventional electronic amplifier types, stabilized by large values of degenerative feedback. The wattmeter is an electrodynamometer type with both current and voltage coils supplied from stabilized amplifiers. A phase shifting circuit converts this to a varmeter. The phase meters are an unconventional feature. One reads angle of the voltage at the metered point and the other reads angle of the current, both with respect to any desired common reference voltage. A switch on the desk allows selection of any generator electromotive force as a reference, or any desired point in the network may be connected as a reference through the transfer jacks. The phase meters employ an electronic circuit[6] which clips and squares the waves before phase comparison, eliminating error caused by amplitude variation.

Insertion of the instruments into the desired circuit is handled by relays, selected by the push buttons. The relays connect the circuits of the desired unit to a Twinax metering bus, which terminates in current shunts and voltage dividers, across which are connected the master instruments of the desk. The shunt introduces a resistance of 0.1 per cent of base value, while the voltage divider inserts a loading of 0.03 per cent on the circuit. The metering bus, connected to all units, inserts some distributed capacity, and the contacts of the switching relays in each unit

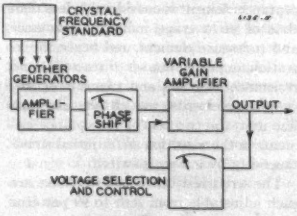

Figure 5. Outline diagram of the generator circuit and operation

insert large lumped capacities in the metering system. These all have been compensated for effectively and the resultant error is negligible.

Design of Units of the Analyzer

The present Iowa State College a-c network analyzer, although a small pilot model, was designed to handle most advantageously the simpler problems for the utilities of the midwest area. In consultation with these utilities, the following choice of numbers of units of the analyzer was made: 4 generator units, 24 line units, 12 load units, 12 capacitor units, 4 tap changer units, and 4 mutual transformer units. Features of the design of each of these units will be given.

Generator Unit

The standard frequency source has an output of a few volts and negligible power. Each unit simulating a generating station of the analyzer must amplify the voltage to the desired base level or higher and provide sufficient power for input to the loads and lines of a given problem. The generator also must have independent means of adjustment for phase angle and magnitude of voltage output.

The generators for this analyzer consist of vacuum tube amplifiers of power output considerably greater than required for rated base output. A generator is shown in Figure 4. Phase angle control is provided in two 180-degree steps through the left hand dial and the "plus-minus" switch on each generator panel, the control operating in the low level amplifier stages. Voltage selection is possible by the right hand dial on the generator panel. With selection of output voltage, an automatic voltage control circuit is set to adjust the amplifier gain and maintain the desired voltage. A block diagram of a generator is shown in Figure 5.

The performance of the automatic voltage control circuit is shown in Figure 6. The control operates to maintain constant voltage to 250 per cent of base or rated output current into a resistance load. This represents zero internal impedance and zero per cent regulation. Above 250 per cent load current, the generator voltage drops because of an internal impedance of about 4.0 ohms. On either leading or lagging load, the voltage regulation is improved over that for resistive load. Contrasting with the generator performance under control is the performance with no voltage control, as shown by the dashed line in Figure 6.

Connected to each generator is a set of instruments to read generated electromotive force, current, and output power, as shown in Figure 7. The instruments are electronically operated and stabilized by degenerative feedback in order to be entirely independent of changes in tube characteristics and line voltage. All in-

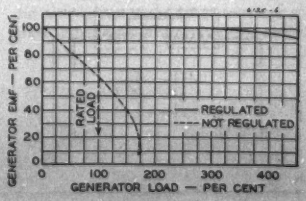

Figure 6. Voltage regulation of the generators for varying output

Figure 7. Individual generator metering panel

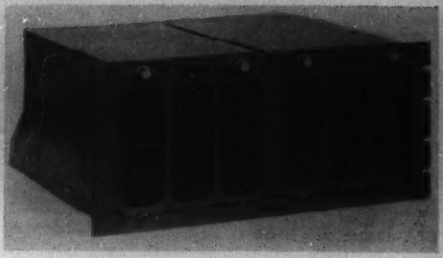

Figure 9 (right). Assembly of a line unit

struments are calibrated in percentage of base values. The wattmeter is arranged with zero center scale so that indications of reverse power flow can be read easily. With the meters permanently connected to each generator output, the loading can be checked continuously, and the effect of adjustments of one generator on the output of other generators in the system can be observed readily.

Mounted below each generator is an inductive reactance panel by which generator reactance up to 99-per-cent base value by 1-per-cent steps may be inserted. Both generator electromotive force and terminal connections are available at the transfer jacks for ready circuit connection.

Line Unit

In reducing an actual system to a model representation on a network analyzer, retention of each line of the system as an entity is highly desirable. In the majority of previous analyzer designs, the series resistance and reactance equivalents have been retained in the analyzer line unit, but shunt susceptance equivalents of all lines emanating from a common bus usually have been added and set up on these analyzers by a single separate capacitive susceptance unit. The direct metering of a line for terminal current conditions, therefore, was impossible. The line unit of the Iowa State College analyzer was designed as an entity containing the shunt capacitive susceptance as well as the series resistance and series inductive reactance. This detail was possible because of the favorable space and cost conditions inherent in the higher frequency design. A schematic wiring diagram of a line unit is shown in Figure 8, and a photograph of a line unit panel is shown in Figure 9.

Either a T- or a π-section design would be electrically satisfactory for the line unit. However, the cost and space requirement of an average capacitive susceptance element is considerably less than that of an average inductive reactance and resistance element, and hence the π-section, requiring one set of reactance and resistance elements and two sets of susceptance elements, was chosen. In each line unit, the two sets of susceptance elements in the π-section are adjusted simultaneously by a 2-gang switch.

The series resistance and reactance are each adjustable from zero to 99 per cent in 1-per-cent steps. The total shunt susceptance is adjustable from zero to 9.9 per cent in one tenth of 1-per-cent steps. Each of these three elements thus was designed in two decades.

Load Unit

The basic elements in the load unit design are resistance and inductive reactance inasmuch as the majority of load conditions in an actual system may be represented by these parameters. In representing load conditions on the analyzer, often the voltage at the load point is an unknown quantity at the time of establishing equivalent resistance and reactance values. If a particular power and power factor are known conditions, an estimate of the voltage usually is made and the corresponding circuit parameters are calculated and set on the analyzer. Measurements then are made of the first approximation of the desired power. If the power is not that desired, a resetting of parameters is necessary. In the Iowa State College analyzer, the resistance and reactance values are viewed electrically through a variable ratio autotransformer, adjustable by 1-per-cent values from 1/1.10 to 1.10. If the first estimate of the resistance and reactance are within approximately plus or minus 20 per cent of the actual values required, the adjustment of the load may be accomplished quite simply by adjusting the turns ratio of the transformer, thus avoiding a recalculation of the individual resistance and reactance parameters. A schematic wiring diagram of a load unit is shown in Figure 10, and photographs of a load unit panel and rear assembly are shown in Figures 11 and 12.

The resistance and reactance elements may be placed either in series or in parallel with one another by the switching plan illustrated in the schematic wiring diagram. This permits more versatility in the application of this unit to a variety of problems.

The resistance and reactance are each adjustable from zero to 9,990 per cent in 10-per-cent steps. Each of these two elements was thus designed in three decades.

The output terminals of the load unit are retained even though for normal load usage this output is closed by a short-circuiting plug. By thus providing the output terminals, the load unit may be used also as a circuit of higher series im-

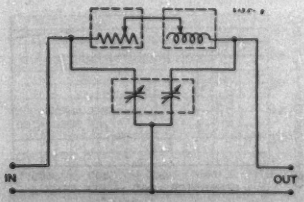

Figure 8. Simplified diagram of the wiring of a line unit

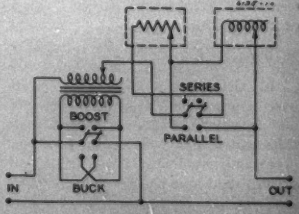

Figure 10. Simplified diagram of the wiring of a load unit

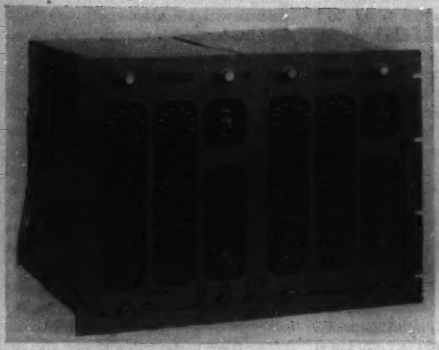

Figure 11 (above). Front panel view of a load unit

Figure 12 (right). Rear assembly of a load unit

pedance rather than a line unit for those applications where such a circuit may be desirable.

The autotransformer utilizing a high frequency low-loss steel core has an equivalent shunt impedance such that the error introduced by the adjusting transformer when used with the base impedance is approximately 0.6 per cent. The equivalent series impedance of the autotransformer when set at full ten per cent is 0.7 per cent. Each of these errors is comparable to the one-half-per-cent accuracy which was the design goal of this analyzer.

Capacitor Unit

Separate capacitor units are provided on the analyzer for increasing the range of the susceptance built into the line units, adding capacitive loading to the load units, or for representing series or shunt capacitors at any point in a system. A photograph of such a panel is shown in Figure 13.

The capacitive susceptance may be used either as a series or shunt element by a switching plan similar to that used in the load unit. The susceptance is adjustable from zero to 99 per cent in 1-per-cent steps. The element thus is designed in two decades.

Tap Changer Unit

Tap changer units are provided for representing networks which do not possess net unity turns ratios around closed loops. The unit is a variable ratio autotransformer adjustable from 1.000 to 1.295 by 0.005 steps. The transformer has a low-loss steel core and in design is similar to the load adjustor transformer of the load unit. The equivalent shunt impedance is practically identical with that of the other unit. Incorporated also is a reversing switch which changes the turn ratio from a step-up to a step-down basis.

Mutual Transformer Unit

A unity ratio 2-winding transformer with an inductive reactance placed across either side is used for representing mutual coupling between circuits of a power system. The mutual transformer, utilizing a low-loss steel core, introduces losses of approximately 0.4 per cent of base power if used across a 10-ohm reactor at full base current. The equivalent series impedance of the transformer is also 0.4 per cent and introduces negligible error of insertion.

Miscellaneous

The Twinax cable from each unit terminates at the transfer panels in two sets of 2-conductor jacks. One pair of duplicate jacks connect to the common and input conductor of the unit and the other pair to the common and output conductor. By the process of extensions from duplicate pairs, a large bus system may be established.

Associated with the input or output terminals on each unit are separate jacks which permit the interconnection of other units inside the point at which the meters are inserted by the relay system. Thus a single instrumentation of a composite group of units is possible when this is desirable, as for example if capacitive loading were added to a load unit by inserting a capacitor unit inside the metering point of a load unit.

Operating Experience

Although commercial operating experience of the analyzer as a whole is rather limited at the present date, such system problems as have been set up on the analyzer have yielded results which check at nodes and loops quite consistently within the design tolerances previously mentioned.

Several 2- and 3-generator problems which have been calculated have been set up on the analyzer, and measured values on these problems likewise have been within the design tolerances of the units and the instruments.

As elements of the analyzer have been completed over a period of the past 15 months, each has undergone extensive testing in the component form; and, where the experimental measurements did not conform to the design tolerance of one-half-per-cent accuracy, further modi-

Figure 13. Panel view of a capacitor panel

A 400-Ampere Sealed Ignitron

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NONMEMBER AIEE

Synopsis: As rectifier capacity is increased, it becomes desirable to use larger capacity rectifying elements. The choice of rectifying element size requires careful consideration in order to provide a complete range with a minimum number of units. The sizes of industrial ignitron tubes for welding control and for rectifier service have been chosen on a preferred number scale providing a proportionate increase at each increment. The development of a 400-ampere ignitron for rectifier service was undertaken to provide the next larger size tube in the series. Development work on the 400-ampere ignitron disclosed that design problems become more complex as the physical size of the tube is increased. The ability of a tube to rectify a given current with a minimum number of arc-backs is affected by circuit duty and by control of ionization, particularly at the end of the current commutating period. None of the factors involved have indicated an upper limit in size, but rather a need for a more exact understanding of the phenomena involved.

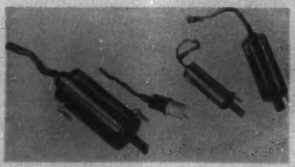

Figure 1. Sealed ignitrons for welder service ranging in capacity from 300 to 2,400 kva at 230 to 600 volts (rms)

THE DEVELOPMENT of the ignitor introduced a new and different concept in the utilization of mercury pool cathodes for mercury arc rectifying devices.[1] The ignitor permitted the starting of a new cathode spot for each conducting period at the precise instant that conduction was desired. With this mechanism it was possible to design mercury pool tubes of the single-anode half-wave type having the control characteristics of the thyratron, the versatility of the half-wave tube in circuit application work, and the very high emission capacity of the mercury pool. This emission capacity seems partly caused by the ability of the cathode spot to divide and subdivide above currents of the order of 15 to 20 amperes until a sufficient number exist to supply the current demand of the circuit in which the rectifying element is connected.

Further recognition of the greater efficiency of the single-anode half-wave design for power conversion work in comparison with the older multianode rectifiers has been made recently in the development of an excitron tube.[2] With this tube, continuous excitation of a cathode spot on the mercury pool is maintained, and control of the starting of the anode current is accomplished electrostatically by means of grids as in the thyratron.

It is the purpose of this paper to review, briefly, the progress that has been made in the development and application of ignitron tubes and to outline some of the design considerations in the development of higher current sealed tubes.

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Status of Ignitron Tube Development and Application

PUMPED IGNITRONS

The largest field of application for continuously evacuated ignitron tanks has been in the electrolytic refinement of aluminum and magnesium. Here, large amounts of direct current are required for a single line of reduction cells. Capacities as high as 30,000 kw, 50,000 amperes at 600 volts are needed. Initially, to supply this capacity, individual rectifiers of the order of 3,000 kw were operated in parallel. The rectifying element of each unit consisted of 12 tanks having a continuous average current capacity slightly over 400 amperes per tank. Continued development supplemented by field experience has increased this capacity so that tanks of 1,000 amperes are practicable.

WELDING CONTROL IGNITRONS

Initial application of permanently evacuated sealed ignitron tubes was made in an entirely new field—that of control and timing for resistance welding.[3]

In resistance welding, two pieces of metal are held together in close contact and a high current passed for a sufficient time to heat the parts to a welding temperature. The parts then are forged together. Control of the time is essential if uniform repetitive welds are to be made. Some progress had been made previously with the use of thyratrons to control the number of cycles in the weld, the current capacity of the thyratron being matched against the welder transformer primary requirements by means of a series transformer. Two ignitron tubes connected in parallel, but with current flow in opposite directions, provide a simple low-inertia switch with sufficient current carrying capacity to conduct the welding transformer primary current directly. In conjunction with thyratrons to initiate conduction, this precise control not only improves the quality of welds in materials

usually fabricated by resistance welding, but also permits materials to be fabricated which heretofore had been considered too difficult to weld. As a result, welding methods have been extended from simple spot welds to line welding (a series of overlapping spots) to sequence control (in which provision is made for preheating, welding, forging, cooling, and annealing periods) and to flash welding. Sealed ignitron tubes developed for this service range in capacity from 300- to 2,400-kva demand for two tubes at supply voltages of 250 to 600 volts (rms). Figure 1 shows the general appearance of the welder ignitrons. All are water-cooled directly except the smallest, in which the heat is transferred to a heavy clamp that in turn may be either air- or water-cooled.

An interesting application of the ignitron contactor principle has been made to provide rapid interruption of the plate power supply in case of arc-over or short circuit in radio transmitters.[4] Ignitron contactors have been placed in each of the three 2,300-volt lines supplying power to the rectifier transformer. Ignition power is supplied through thyratrons. In case of fault, overcurrent operates small high speed d-c relays in the transmitting tube circuits that block the thyratrons, and the ignitron tubes in turn cease conduction. Interruption of fault currents occurs in slightly over one cycle of the 60-cycle supply frequency. Damage to the transmitter equipment from flashover and to the transmitter tubes is negligible.

Rectifier Ignitrons

Rectifier duty is more severe than welder control and it was necessary to modify the design of the sealed tubes somewhat, as discussed later, in order to provide service essentially free from arc-back. Two sizes of tubes were developed which in 300-volt d-c service have continuous average current ratings per tube of 100 and 200 amperes. At 600 volts, the current capacities are 75 and 150 amperes. In addition, overload capacity is required since rectifier equipment for industrial, mine, and railway service has standard 2-hour and 1-minute ratings. These standards vary, depending on the service, from 125 to 150 per cent at the 2-hour point and from 200 to 300 per cent at one minute. To meet these requirements, the continuous or design capacity of the tubes must approach the overload requirements because the mass of the tube electrodes is small, in general, and there is relatively low heat storage capacity.

With these two sizes of tubes, it was possible to provide sealed ignitron rectifier equipment ranging in capacity from 75 to 500 kw at 300 volts, and from 100 to 1,000 kw at 600 volts by proper choice of the circuit and number of tubes.[5] Trial installations were made in the industrial, mining, and electrolytic field, and for building service d-c supply. Sufficient experience had been obtained at the beginning of World War II to provide field tested and proved equipment for the great industrial expansion that took place.

400-Ampere Sealed Ignitron

In the initial development of steel envelope sealed ignitron tubes, there were two predominant considerations—vacuum life and ignitor life. Rectifier duty, in particular, is continuous in nature and it is essential that sealed tubes for this service have a long life to avoid the interruptions of frequent replacements. Experience has demonstrated amply that tubes properly degassed and tightly sealed retain the required vacuum conditions for years. In fact, the action of the arc and the walls of the tube exert a considerable cleanup action which tends to improve the initial vacuum.[6] Under ordinary service conditions, ignitors show very little wear or erosion. Under improper conditions, such as accidental reversal of the ignitor current, the life may be very short—a matter of minutes—since a cathode spot then forms on the ignitor and material is blasted away rapidly. Actual life of some of the tubes in initial installations has exceeded five years with these tubes still in service.

With substantiation through field experience of the basic factors of vacuum and ignitor life and the excellent performance of the higher current rectifiers for aluminum and magnesium reduction, it was felt that development of the next larger size of sealed ignitron tube was desirable and could be undertaken.

Size

It is fully as important to choose a proper series of sizes in electronic tubes as in other electric or mechanical devices. Preferred number scales which provide a proportionate increase in size or capacity at each increment offer a logical means of determining the number of sizes required to serve a given field. Sizes for both the welder and rectifier ignitron tubes were established on this basis. In the case of the rectifier ignitrons, the series 25, 50, 100, 200, 400, 800, 1250, 2500 gives a satisfactory spacing in average current per tube. At the lower end of the scale, 25 amperes and below, thermionic-cathode tubes of the thyratron type are used because of the reduction in required auxiliary equipment. The number of sizes required above the 400-ampere point will depend primarily on application trends. In general, it is preferable to use larger sized tubes rather than increased numbers for increased capacity, provided proper wave shape and induction co-ordination factors are maintained.

Design

Ignitron tubes are basically heat-transfer devices in which maximum temperatures establish the limiting operating conditions as in other forms of electric equipment. The limiting temperatures are not those, in general, at which gradual deterioration or burning takes place, but rather those at which complete failure of the rectifying properties occur. Such failures rarely cause destruction of the rectifying element itself unless the arc-backs are allowed to persist. Normally, restoration of conditions below the limiting ones restores the rectifying action.

The insulating patch theory developed by K. H. Kingdon and E. J. Lawton seems to offer the most reasonable and consistent explanation of the cause of arc-back.[7] Briefly, it is assumed that small microscopic insulating particles exist on the surface of the anode or are carried there by the vapor stream. These patches become charged from the ionization present. If the charge becomes sufficiently great and the distance separating the charge from the anode is sufficiently small, field emission will release enough electrons to establish a glow discharge. The resulting increase in ionization favors the establishment of a cathode spot on the anode, which is followed by arc conduction of current in the reverse direction. The probability of exactly the right conditions occurring depends on the density of ionization in the immediate vicinity of the anode, the rate of ion collection, the frequency of trial, and the size and leakage resistance of the insulating patch. For a given design, the majority of the factors depend on or are related to circuit requirements so that a knowledge of these provides a basis for predicting tube performance.

From the tube design view point, it is difficult to isolate the effects of the factors influencing arc-back since they are interrelated and interdependent. The more important ones are as follows:

1. Vapor pressure.
2. Ionization.
3. Anode current.
4. Anode voltage.
5. Circuit duty.

Vapor Pressure

Energy losses occur in an ignitron tube as a series of pulses. These pulsations are averaged by the mass of the enclosing envelope to an even flow of heat which is removed by the water-cooling. The water temperature therefore determines a base or datum plane above which the instantaneous pressure rises during the conducting cycle. The instantaneous pressures are the result of vaporization of mercury by the action of the cathode spot. Mercury is vaporized at a rate of approximately 7.2×10^{-9} grams per coulomb, and this mercury blast creates pressures during the conducting period far in excess of the pressure determined by the wall temperature. The pressure during conduction is of little importance as regards arc-back, except as its magnitude influences the ability of the condensing walls to reduce the pressure at the end of conduction to a value below the breakdown point. A typical pressure breakdown curve for static conditions in mercury is shown in Figure 2. Since the pressure waves travel with a velocity approximately that of sound, there is a time lag between the current and the corresponding instantaneous pressure at the end of conduction which tends to delay deionization. This lag increases as the size of the tube increases.

In addition to the vaporized mercury, the action of the cathode spot ejects relatively large (visible) mercury droplets which travel at a rate very much slower than the pressure wave. The droplets may be observed in glass tubes by blocking out the glow during conduction with a synchronously rotating slotted disk and by illuminating the vacuum space with the light from a tungsten filament lamp. The initial velocities of individual drops vary widely since droplets are visible at the top of their trajectories over nearly the entire length of the tube. These droplets undoubtedly create high transient pressures when they strike relatively high temperature objects, and because of their random character may account for some of the arc-backs that are found to occur late in the inverse cycle when both the residual ionization and inverse voltage have decreased appreciably from their maximums.

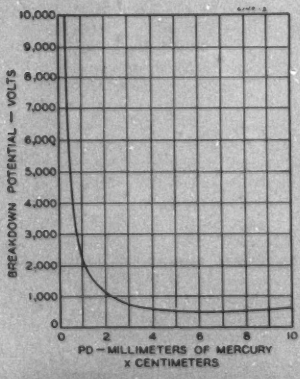


Figure 2. Breakdown voltage between two electrodes in mercury vapor as a function of the product (Paschen's law) of the vapor pressure *P* and the gap length *D*

Ionization

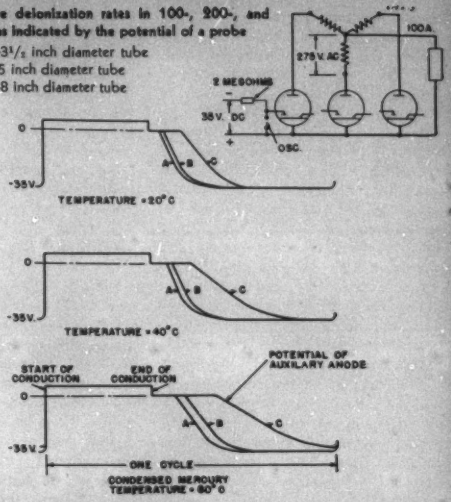
The problem of ionization becomes increasingly important as the size and capacity of the tube is increased.

Under low pressure conditions, the mean free path of the ions is relatively long, and the arc voltage needed to produce the required ionization is relatively high. Under extremely low pressures, there is a condition in tubes having constricted arc paths where there are insufficient ions to neutralize the space charge and for an instant the tube behaves as though it were a high vacuum tube.[6] The current is reduced abruptly, and this change in conjunction with associated circuit inductance produces high voltage surges. The point at which pressures become low depends largely on the tube design. In tubes of small volume and open construction, the possibility of constriction surges is remote at any temperature above zero degree centigrade (vapor pressure, 0.16 micron) because the action of the cathode spot very rapidly establishes the vapor density required to provide the necessary ions. As the size of the tube increases, and particularly as grids are added to control the ionization, the minimum pressure must be increased. In multiple grid high voltage tubes, minimum pressures of the order of four to eight microns (35–45 degrees centigrade) are required for currents of 4,000 amperes. The minimum pressures usually are determined by the short-circuit current that the tube may be required to conduct, rather than the normal load currents.

At the end of conduction, the intensity of residual ionization becomes extremely important because of its direct relation to arc-back. In tubes of small volume, the deionization rate is rapid and equilibrium between ionization and anode current is reached quickly so that the ion density is relatively low when inverse voltage is applied at the end of commutation, or transfer of current from anode to anode. As the cross section and volume of the tube increase, for higher capacities, the volume of ionized gas increases and the time required for the ions to diffuse to the walls is increased, with the result that the density of ionization at the end of conduction is correspondingly higher. Figure 3 shows the time required for the ionization to decay to a given value for a fixed value of anode current in the 100-, 200-, and 400-ampere sizes of tubes. The curves repre-

Figure 3. Comparative deionization rates in 100-, 200-, and 400-ampere tubes as indicated by the potential of a probe

A—3¹/₈ inch diameter tube
B—5 inch diameter tube
C—8 inch diameter tube



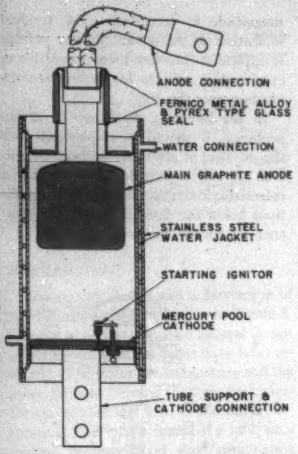


Figure 4. Cross section of a 2,400-kva control ignitron

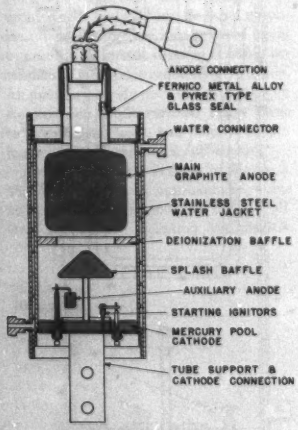


Figure 5. Cross section of a 200-ampere rectifier ignitron

sent the auxiliary anode-to-cathode voltage as seen on a cathode ray oscilloscope, with the auxiliary anode used as a probe and connected to a negative bias to collect positive ions as indicated in the connection diagram insert. The point in the curves at which the auxiliary anode voltage begins to increase negatively indicates the time required for the ionization to decay to a value just at which the probe current can be supplied without an increase in voltage. The effects of increased tube diameter, arc volumes, and particularly increased vapor density are clearly shown.

In the development of the 400-ampere tube, it was expected that the general design of the smaller tubes could be extended to this size. However, operation tests indicated that both the ionization density and time of deionization must be decreased. One of the most effective methods of accomplishing this in the larger tubes is to enclose the anode within a grid. The grid functions primarily as a shield to isolate the anode from the ionization in the arc chamber. The small volume of ionization between the grid and anode insures rapid deionization of this space. Probably of equal importance is the current density level that can be collected on any part of the anode.

Anode Current

The magnitude and wave shape of the anode current influences the magnitude and wave shape of the vapor pressure wave and affects the ionization density. These factors depend, in general, on the mode of operation of the rectifier circuit employed. The delta 6-phase double-Y circuit (proposed AIEE Standards nomenclature) commonly is used and in this circuit there is a ratio of three to one between the peak and average currents. This ratio usually varies from two, three, four, six to one, depending on the type of circuit. At the end of conduction, the current wave shape, and particularly the magnitude of the ionization resulting from the current, depends on both the commutating reactance of the transformer and supply and the voltage that is available to transfer the current from one phase to another.

Anode Voltage

The degree of positive ion bombardment and the thickness of the ion sheathes that form around the anode during the negative part of the cycle are functions of the magnitude of the inverse anode voltage. This voltage therefore influences the factors involved in arc-back directly. The magnitude of the inverse voltage depends on the circuit and is higher for circuits having low ratios of peak-to-average currents and lower for those having high ratios. Two periods in the inverse voltage wave are of particular interest. The initial inverse voltage occurs at the end of commutation at the time the residual ionization is highest. Its magnitude depends on the circuit, the transformer commutating reactance, the current commutated, and the amount of phase control. The maximum inverse voltage depends on the circuit and usually occurs later in the

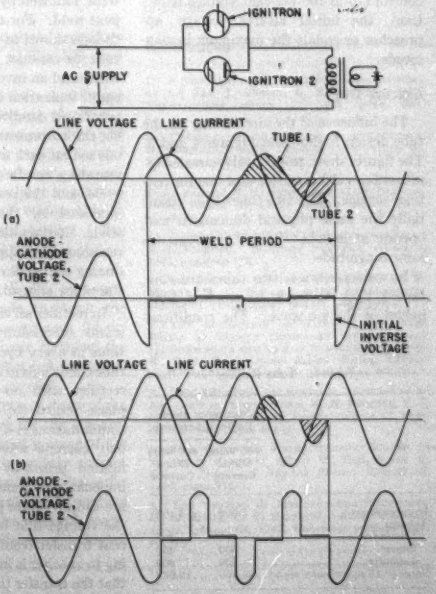


Figure 6. Tube voltage and current wave shapes for welding control operation

(a). No phase retard
(b). Approximately 30 degrees phase retard

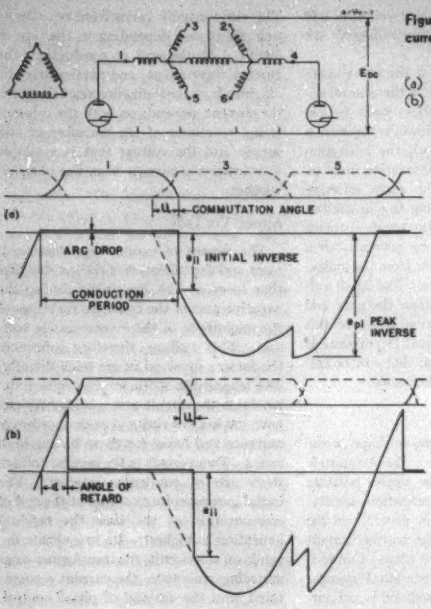


Figure 7. Tube voltage and current wave shapes for rectifier operation

(a) No phase retard
(b) Approximately 30 degrees phase retard

cycle when the residual ionization is reduced. Under large amounts of phase control (70-to 100-per-cent voltage reduction), the initial inverse voltage approaches or equals the maximum in magnitude.

Circuit Duty

The influence of the circuit duty on the tube design is shown in Figures 4 and 5. The figures show, respectively, a sealed ignitron for welder service and one for rectifier service. The two tubes have essentially the same physical dimensions and operate at inverse voltages of about the same magnitude.

In welder service, two tubes are connected back to back to conduct both halves of the a-c wave. The conditions for welder service are shown in Figure 6 for several current cycles in a single spot weld, followed by an off period before the next weld. For the no-phase retard conditions shown in Figure 6a, only the last tube to conduct in the final cycle must withstand an inverse voltage when appreciable ionization is present. Under phase controlled conditions as shown in Figure 6b, the current wave becomes discontinuous so that each tube must withstand commutating conditions in each conducting cycle, and the resulting duty therefore is increased by the increased number of trials. Recognition of this is made in the recommended application practice by reducing the peak current in proportion to the phase control.

Table I. Tube Ratings

	Maximum Anode Current, Amperes	
	300 Volts Direct Current	600 Volts Direct Current
Instantaneous	3,600	2,400
Average		
Continuous	400	300
2-hour	600	450
1-minute	800	600
Surge (0.15 second maximum)	25,000	19,000

In rectifier service, the tubes must withstand successfully commutating conditions in every cycle. Figure 7 shows the tube conditions in a delta 6-phase double-Y rectifier with no-phase retard (a) and phase retard (b). The tube current at commutation is a segment of a short-circuit current wave whose magnitude is limited primarily by the commutating impedance of transformer and by the tube arc-drop. Under phase retard conditions, the voltage that is available to force current transfer from one transformer winding to another is increased, with the result that the transfer time of a current of given magnitude is decreased. The residual ionization at the instant inverse voltage is applied is therefore higher, and this in combination with the higher inverse voltage increases the duty.

In the foregoing discussion of design problems, it should be emphasized that the problem of arc-back has been considered at limiting conditions and that a reasonable reduction in operating conditions below the limit results in performance practically free from arc-back.

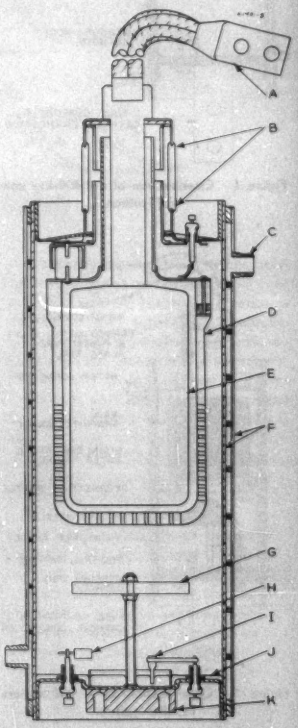


Figure 8. Cross section of the 400-ampere ignitron showing the general design

A—Anode connection
B—Fernico metal alloy and Pyrex type glass seal
C—Water connection
D—Graphite grid
E—Main graphite anode
F—Stainless steel water jacket
G—Splash baffle
H—Auxiliary anode
I—Starting ignitors
J—Mercury pool cathode
K—Tube support and cathode connection

Table II. Combinations of Tubes and Circuits

Kilowatt Output 300 Volts	Kilowatt Output 600 Volts	Number of Tubes	Circuit
400	750	6	Delta 6-phase double-Y
500	1,000	6	Delta 6-phase double-Y
750	1,500	12	Delta, 12-phase quadruple zig-zag Y
1,000	2,000	12	Delta 12-phase quadruple zig-zag Y

Construction

The general design and construction of the 400-ampere tube is shown in Figure 8. The essential materials and general design of the earlier ignitron tubes have been retained. The water-cooling jackets and the inner cylinder forming the vacuum chamber are of stainless steel to minimize corrosion. The anode insulating and supporting bushing is of the fernico-glass sealing combination that has proved very satisfactory, not only from the vacuum tightness standpoint but from the viewpoint of strength and shock resistance as well. Anode and grid are of special graphite. Two ignitors are incorporated again to provide for circuit reversal or other accidents. Only one is required for ignition. An auxiliary anode provides cathode spot stability for anode currents below three to five amperes peak, and permits simplification of the ignition circuit control.

A completed tube is show in Figure 9. The water jacket is approximately nine inches in diameter and 22 inches tall. Over-all height, including the flexible anode lead, is 40 inches, and the tube weight is approximately 95 pounds.

Figure 9. A completed 400-ampere sealed ignitron

In the larger sizes of tubes, the materials used in the construction become an increasing proportion of the tube cost, and, even though warranties protect against loss from early failure, it becomes desirable to provide in the design the possibility of repair. In this tube the header closing welds are of the fusion type rather than resistance seam welds. This permits removal of the headers with relative ease for inspection or repair.

Performance and Rating

Essential ratings of the 400-ampere tube are given in Table I, and Table II shows possible combinations of tubes and circuits to provide industrial rectifiers of standard capacities at the 300- and 600-volt levels.

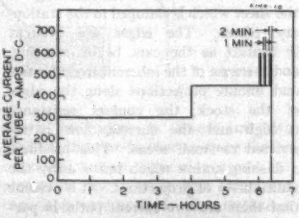


Figure 10. A 600-volt operation test at rated continuous 2-hour and 1-minute load currents for zero phase retard

Rectifier performance tests usually are made on the load increment plan for a chosen water temperature and flow and at the desired operating voltage levels.[9] The commutating impedances are adjusted to give output voltage regulation and short-circuit currents comparable to these expected in actual service. The load usually is absorbed by motor generator sets.

Prior to determining limits, an operation run usually is made to check the performance at rated continuous 2-hour and 1-minute loads. Figure 10 shows the time-current plot of such a run for operation at 600 volts direct current.

Figure 11 shows the general shape of the load limit current curve for the 400-ampere ignitron as the output voltage of the rectifier is reduced progressively to zero by means of phase control. Limits as far as the tubes are concerned are determined by arc-back. Under phase retard conditions, the combined effects of a higher initial inverse voltage and greater ion density produce a higher tube duty, which is reflected by a reduction in load current.

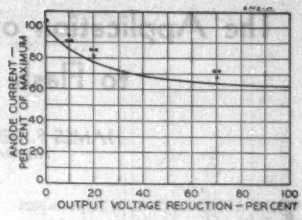


Figure 11. Continuous average anode current, determined by load limit tests, as a function of output voltage reduction by phase control

The dots indicate arc-backs

Conclusion

The development of the 400-ampere sealed ignitron revealed no factors which would tend to limit the size and capacity that could be designed. Undoubtedly, larger tubes would require different treatment and probably different forms. The development did show the very great part played by ionization and the need, in spite of the excellent fundamental work that has been done, for additional work with particular emphasis on the problem of rectification.

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The Application of Series Capacitors to Flash Welders

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THE APPLICATION of series capacitors to spot, projection, and seam welders no longer presents any difficult problems, and they have been used successfully with these types of welders for several years.

Essentially, enough capacitive reactance is placed in the primary circuit of the welder transformer to neutralize the inductive reactance of the welder. This theoretically produces unity power factor and reduces the kilovolt-ampere demand to the level of the kilowatt demand. Since the voltage across the capacitor units is directly proportional to the current flowing through them, units must be selected with a voltage rating high enough so that this rating is not exceeded unless they are protected by an overvoltage device.

The flash welder, however, presents an entirely different problem since the welding operation is composed of two phases which differ widely in both power factor and kilovolt-ampere demand.

The first phase is termed flashing and occurs when the pieces to be welded are brought in contact and heated to a plastic state by the passage of the current as it flows from one piece to the other. There is some doubt as to whether this current flow is caused by metallic or gaseous conduction. However, we do know that there is not good contact between the two pieces, and we will speak of the condition during current passage as an arc. The flashing kilovolt-ampere demand is less than the final upset phase, the power factor is relatively high, and the wave shape of the current is rather irregular, as shown in Figure 1.

When the plastic temperature has been reached, the upset phase takes place. Here the pieces are forced together quickly and are forged, producing the complete weld. Since the resistance at the weld region is lower at upset than when flashing, the kilovolt-ampere demand is greater, the power factor lower, and because of the absence of arcing, the wave shape of the current is smooth, as illustrated in Figure 2.

An example of this type of machine is the barrel welder. Figure 3 is a simplified drawing of the essential parts. Note that as the cam appearing at the extreme right revolves, the movable platen, in which is clamped one edge of the sheet forming the barrel, moves slowly toward the edge of the sheet which is clamped in the stationary platen. The edges are brought in contact as the cam begins rotating, and, because of the inherent irregularities and minute projections along the edges of the stock, the contact resistance is high and the current flow is restricted to small areas. This produces a flashing action which burns away the multiplicity of projections. It is evident that there are two current paths in parallel: one short path through the weld region and the other, a longer path, through the cylinder. The relatively high resistance offered by these two paths in parallel therefore results in a comparatively low kilovolt-ampere demand and high power factor.

When the upset block on the cam meets the movable platen, the edges of the stock are forced together, the arc extinguished, and, because of the resulting decreased resistance, the current flowing through the weld region increases greatly. The ratio of the resistance to the inductive reactance of the secondary circuit decreases with an accompanying decrease of power factor.

A series of tests were made on a standard 350-kva 440-volt 42-inch barrel welder welding a standard 16-gauge 55-gallon drum to determine the possibility of applying series capacitors to reduce the kilovolt-ampere demand and increase the power factor.

Oscillograms were taken before any power factor correction was attempted and it was found that the demand during flashing was about 350 kva at 92 per cent power factor, and at upset the demand increased to 1,200 kva at a power factor of 48 per cent. The relative magnitudes are shown graphically in Figure 4.

Suppose we add enough capacitance to

Figure 1. Oscillogram of current and voltage during flashing

Figure 2. Oscillogram of current and voltage during upset

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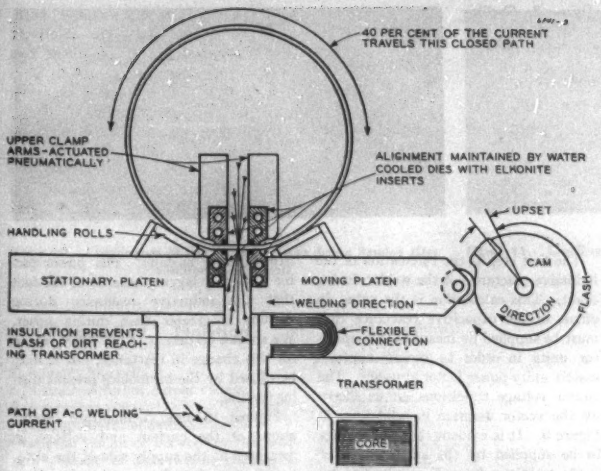


Figure 3. Essential parts of a drum welder

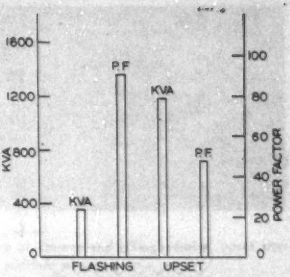
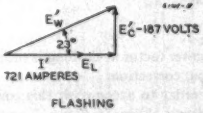


Figure 4. Initial uncorrected values of kilovolt-ampere demands and power factors



the primary circuit of the welder to obtain approximately unity power factor during the flashing period. Proceeding exactly as is done in applying series capacitors to any other type of welder, it is found that 29 230-volt capacitors are required. Figure 5 gives vectorially the voltages existing in the circuit at this time.

During the upset stage of the weld, the current increases, thereby producing a proportional increase in the primary current which now flows through the capacitor bank. This results in a voltage drop across the capacitors which is approximately 150 per cent greater than the maximum permissible voltage of the units. Of course, units with a greatly increased voltage rating could have been chosen initially, but the number required would have been approximately four times that actually selected, so that this is clearly not an economical solution. The demand also has increased to a value approximately 25 per cent greater than it was before the capacitors were applied. The upset portion of Figure 5 gives these values.

Let us now increase the capacitance to that required to correct the upset portion of the weld to unity power factor. We find that it is necessary to use 36 575-volt units. However, the resulting series circuit at upset impresses a voltage of about $2^1/_2$ times the normal supply voltage across the welder transformer, as shown in Figure 6. There are two methods that can be used to maintain the secondary voltage appearing across the platens at the value it was before the capacitors were applied. One method is to increase the welder transformer ratio, and the other is to use a step-down transformer in the supply circuit. In this instance let us choose the first method and increase the transformer ratio.

As shown in the flashing section of Figure 6, we immediately meet complications during the flashing period since the characteristics of the circuit now are such that the voltage impressed on the welder transformer primary is reduced to 60 per cent of that required for proper flashing. This would result in an imperfect weld.

We now are able to conclude that, when there is an appreciable difference between the flashing and upset demands, we will have one of two undesirable conditions present if we apply series capacitors to flash welders, according to conventional theory:

1. Correction of the flashing demand will result in excessive condenser voltage during upset.
2. Correction of the upset demand will result in a welder transformer voltage lower than that required for proper flashing.

Since, in general, it is not economical to use high voltage capacitor units, we will provide a means of increasing the voltage across the welder transformer during the flashing period and use a value of capacitance which will give unity power factor during upset, since

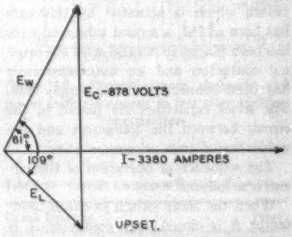


Figure 5. Vector diagrams of currents and voltages existing when the flashing period is corrected to unity power factor

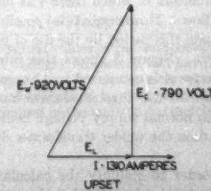


Figure 6. Vector diagrams of currents and voltages existing when the upset period is corrected to unity power factor

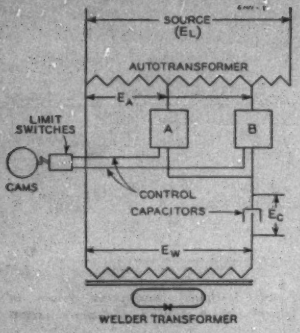


Figure 7. Schematic diagram of circuit used in test

Figure 8. Oscillogram of contactor switching interval

the power factor at flashing is rather high without correction.

In order to accomplish this condition, the circuit shown in Figure 7 was made. A cam has been placed on the shaft which rotates the platen-moving cam, a limit switch which is actuated by this cam has been added, a second tube contactor has been placed in parallel with the original contactor, and an autotransformer has been connected in the supply line. The series capacitors are placed in the circuit between the contactors and the welder transformer primary winding.

The sequence of operation of the circuit is as follows.

When the limit switch is closed, contactor *B* is closed and contactor *A* is left open. The tap on the autotransformer to which contactor *B* is connected is selected so that approximately normal supply voltage is impressed on the welder transformer. This energizes the circuit correctly for the flashing operation. The added cam is adjusted so that contactor *A* is closed and contactor *B* is opened about one cycle before the platen-moving cam starts the upset movement. This adjustment was necessary as there was an interval of one cycle during the switching of contactors in which there was no current flow. However, it is possible to eliminate this period by the use of proper controls. Figure 8 shows this interval. Contactor *A* is connected to a lower voltage tap on the autotransformer and results in normal supply voltage being impressed on the welder transformer during upset.

In order to simplify the calculations, the assumption is made that the source is of infinite capacity. This assumption changes the values slightly from those actually existing during the tests.

The first step is the calculation of the inductive reactance of the welder during upset. This calculation is the value, in ohms, of the capacitive reactance that must be supplied by means of the capacitor units in order to obtain approximately unity power factor at upset. The circuit voltage conditions are as shown by the vector diagram in solid lines in Figure 9. It is evident that the voltage to be supplied by the autotransformer is the welder voltage E_W multiplied by the power factor during upset, plus the tube contactor drop of approximately 15 volts.

The next step is the determination of the circuit constants during flashing. The net reactance is the difference of the capacitive and inductive reactances. This value then is combined vectorially with the flashing resistance to find the resulting impedance. The voltage at the autotransformer then must be equal to this impedance multiplied by the primary flashing current. This current is approximately equal to that occurring during the uncorrected flashing condition. See Appendix II for exact calculation.

The vector diagram composed of broken lines illustrates the voltages existing during flashing. The power factor is slightly lagging because of the fact that the inductive reactance during flashing is greater than during upset. We are not certain as to the exact reason for this change in reactance, but it may be caused by the harmonics present during flashing.

Figures 10 and 11 illustrate oscillograms of the current and voltage as measured at the supply side of the autotransformer after the capacitors had been applied. Note that the power factor during upset is not quite unity and that the power factor during flashing is less than at upset.

Figure 12 shows graphically a comparison between the kilovolt-ampere demand and power factors before and after applying correction in the actual test, the dashed lines giving the corrected values.

It is evident from an examination of Figure 12 that while the low kilovolt-ampere demand and high power factor of the flashing phase has not been altered appreciably, the upset kva demand has been reduced to approximately one-third of its uncorrected value, and the power factor has been increased from 48 to 95 per cent.

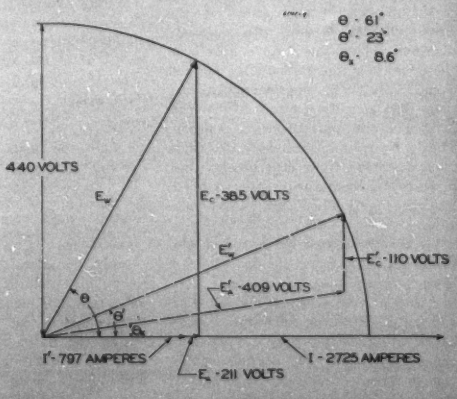


Figure 9. Vector diagram of currents and voltages existing during flashing and upset after capacitors have been applied in final arrangement

Figure 10. Oscillogram of current and voltage during flashing after addition of capacitors

Figure 11. Oscillogram of current and voltage during upset after addition of capacitors

Appendix I. Notation

E_L = supply line voltage
E_A = autotransformer output voltage
E_C = capacitor voltage
I = output current of autotransformer
θ = angular difference between current and voltage in high tension winding of welder transformer

The foregoing refer to upset values. With prime notation they refer to flashing values.

θ_x = phase difference between current and voltage in supply line during flashing after capacitors had been applied

Appendix II. Calculations

Upset period:

$$Z = \frac{E_L^2 \times 10^{-3}}{\text{kva}} = \frac{440^2 \times 10^{-3}}{1{,}200} = 0.161 \text{ ohm}$$

$$X_L = Z \times \sin 61 \text{ degrees}$$
$$= 0.161 \times 0.875$$
$$= 0.141 \text{ ohm}$$

Therefore $X_C = X_L = 0.141$ ohm and power factor becomes theoretically unity.

$$E_A = E_L \times \cos 61 \text{ degrees}$$
$$= 440 \times 0.48$$
$$= 211 \text{ volts}$$
$$E_C = E_W \times \sin 61 \text{ degrees}$$
$$= 440 \times 0.875$$
$$= 385 \text{ volts}$$

$$\text{Corrected kva} = \text{uncorrected kva} \times \cos 61 \text{ degrees}$$
$$= 1{,}200 \times 0.48$$
$$= 575 \text{ kva}$$

$$I(\text{corrected}) = \frac{\text{kva (corrected)}}{E_A \times 10^{-3}}$$
$$= \frac{575}{211 \times 10^{-3}}$$
$$= 2{,}725 \text{ amperes}$$

Flashing conditions:

$$Z' = \frac{E_L^2 \times 10^{-3}}{\text{kva}}$$
$$= \frac{440^2 \times 10^{-3}}{350}$$
$$= 0.554 \text{ ohm}$$
$$X'_L = Z' \times \sin 23 \text{ degrees}$$
$$= 0.554 \times 0.39$$
$$= 0.218 \text{ ohm}$$
$$X_L(\text{net}) = X'_L - X_C$$
$$= 0.218 - 0.141$$
$$= 0.077 \text{ ohm}$$
$$R' = Z' \times \cos 23 \text{ degrees}$$
$$= 0.554 \times 0.92$$
$$= 0.51 \text{ ohm}$$

Thus the power factor with capacitors is

$$\cos^{-1} \tan \frac{X_L(\text{net})}{R'}$$

$$\tan \theta_X = \frac{X_L(\text{net})}{R'}$$
$$= \frac{0.077}{0.51}$$
$$= 0.151$$
$$\theta_X = 8.6 \text{ degrees}$$
$$\cos \theta_X = 0.988$$

Power factor = 98.8 per cent

$$E'_A = \frac{E'_W \times \cos 23 \text{ degrees}}{\cos 8.6 \text{ degrees}}$$
$$= \frac{440 \times 0.92}{0.988}$$
$$= 409 \text{ volts}$$
$$E'_C = E'_W \times \sin 23 \text{ degrees} - E'_A \times \sin 8.6 \text{ degrees}$$
$$= (440 \cdot 0.39) - (409 \cdot 0.1495)$$
$$= 171 - 61.2$$
$$= 109.8 \text{ volts}$$

$$\text{Kilovolt-amperes (corrected)} = \frac{\text{kva} \times \cos 23 \text{ degrees}}{\cos 8.6 \text{ degrees}}$$
$$= \frac{350 \times 0.92}{0.988}$$
$$= 326 \text{ kva}$$

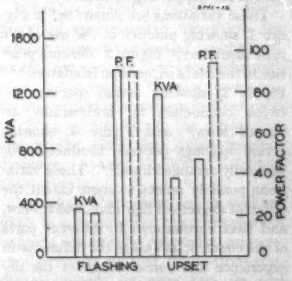


Figure 12. Kilovolt-ampere demands and power factors measured in test after addition of capacitors

Table I. Circuit Constants Before Correction

Circuit Constant	Value
Flashing	
Kva	350
Power factor	92 per cent
θ	23 degrees
E_L	440
Upset	
Kva	1,200
Power factor	48 per cent
θ	61 degrees
Supply voltage	440

$$I(\text{corrected}) = \frac{\text{kva (corrected)}}{E'_A \times 10^{-3}}$$
$$= \frac{326}{409} \times 10^{-3}$$
$$= 797 \text{ amperes}$$

The actual values of the autotransformer output voltages necessarily will have to be approximately 15 volts greater than the values as calculated to compensate for the voltage drop in the ignitron contactors.

Co-ordination of Insulation and Spacing of Transmission Line Conductors

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FELLOW AIEE

A SURVEY of practice on existing transmission systems shows, for the same operating voltage, wide variations in the insulation used. Also, wide variations occur in the spacing between conductors and from them to grounded members of the supporting structure.

These variations are illustrated in Figure 1, showing practice in the use of pin type insulators;[1] Figure 2, showing practice in the use of suspension insulators;[2,3,4] Figure 3, showing actual spacings between conductors for horizontally arranged lines;[4] and Figure 4, showing actual spacings between conductors for vertically arranged lines.[4,5] These variations possibly reflect to some extent the different degrees of lightning, wind, snow, and sleet encountered in different parts of the country, as well as the difference in experience and conservatism of the designers.

A recent committee report[4] gives data on 35 transmission lines in the 190- to 287.5-kv range. In this report is given a comparison of the impulse flashover of the insulators and the flashover from the conductor to the structure through air, with the conductor swung at 30 degrees from the vertical. In many cases the flashover to the structure through air is considerably less than the flashover of the insulators, indicating a lack of co-ordination in the design.

It is obvious from the preceding discussion that very little guidance can be obtained from existing lines as to the suitable number of insulators and spacings for projected transmission lines of various voltages. The writer, therefore, has undertaken to set up criteria for such insulation and spacings which will offer a guide for those engaged in this work, and which will be consistent for the various voltages.

In order to simplify the problem, the present study will apply mainly to steel tower lines with suspension insulators, although the question of wood pole lines and pin type insulator lines will be touched upon.

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Criteria for Minimum Line Insulation

As a basis for the selection of the minimum line insulation, the following criteria are suggested:

1. The 60-cycle wet flashover must equal or exceed the voltages expected from faults and switching surges. The maximum to be expected from these causes is five to six times normal line-to-neutral voltage. These voltages may be reduced by proper neutral grounding, by the use of breakers with minimum tendency for restriking, and by adequate lightning arrester protection. Under the most advantageous conditions, the upper limit of low frequency voltages may be taken as 3 to 3.5 times normal line-to-neutral voltage, and the 60 cycle wet insulator flashover should equal or exceed this value.

2. The impulse flashover should equal or exceed the standard basic impulse insulation level for the terminal equipment.[6]

In Table I are given the 60-cycle dry and wet and impulse flashover values of standard suspension insulators, ten inches in diameter and spaced $5^3/_4$ inches apart.[7]

In Table II are given 60-cycle and impulse flashover values for standard rod gaps.[7] These values may be used for gaps in air between conductors, between conductors and tower, and so forth.

In Table III, column 2, are given for the standard insulation classes the number of insulator disks spaced $5^3/_4$ inches apart, whose wet 60-cycle flashover will equal or exceed 3.5 times line-to-neutral voltage. This is the smallest number of insulators which will have an impulse flashover equal to or greater than the basic impulse insulation level.

Also given in Table III are the numbers of disks whose wet 60-cycle flashover will equal or exceed 4, 4.5, and 5 times the line-to-neutral voltage. In column 6, for comparison, are given the numbers of disks representing average practice, from Figure 2.

It will be noted that average practice follows column 5 up to and including 115 kv, column 4 for 138 to 230 kv inclusive, and column 3 for 287 and 345 kv. These

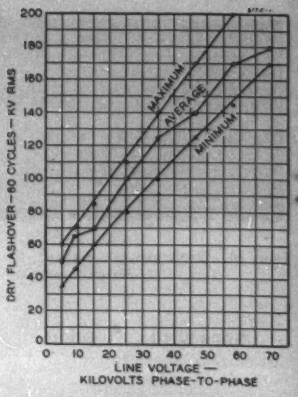


Figure 1. Practice in the use of pin type insulators

average values are from a curve. Actually, the only 287-kv lines in existence have the equivalent of 21 disks spaced $5^3/_4$ inches apart,[4] and so far there are no 345-kv lines. The tendency to use a greater relative insulation at the lower voltages is similar to the tendency to be found in the insulation of apparatus.

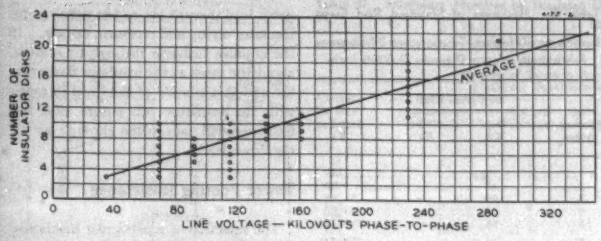
Co-ordination of Spacing With Insulation Level

With each level of insulation, there is a proper spacing between conductors and to the steel structure to develop the full strength of the insulator string selected. Let us take the minimum spacing to the steel structure *A* (Figures 5 and 6) as a spacing that will have an impulse flashover ten per cent greater than the impulse flashover of the insulator string.

Spacing *B* (Figures 5 and 6), the horizontal distance from conductor to tower when the conductor is hanging vertically, will be such that when the conductor is swung to 30 degrees from the vertical the impulse flashover from conductor to tower (spacing *A*) will be ten per cent greater than the insulator string flashover. It is assumed that during the summer season, when lightning prevails and there is no ice or snow, 30 degrees is ample to consider for the conductor swing.

Having determined spacing *B* from conductor to tower, spacing *D* between conductors for the horizontal arrangement (Figure 5) becomes two times spacing *B*, plus the width of the tower leg.

For the vertical arrangement (Figure 6), the spacing between horizontal planes through the conductors, spacing *C*, is a



minimum of two times the spacing A, since the insulator string itself has a length approximately equal to spacing A. On the tower illustrated in Figure 6, on account of the slope of the crossarm bracing, the spacing between conductor planes naturally will be somewhat greater than $2A$. In other types of towers without crossarm bracing, this may not be the case, and the minimum spacing $2A$ can be used.

In order that the conductors may be fully shielded from direct strokes, it has been found that the two overhead ground wires are necessary, either for horizontal or vertical arrangement of conductors. If the two ground wires are placed close together, they blanket each other and the full benefit of the two wires is not secured. The effect is much the same as the effect of two rods driven in the ground. If the rods are close together, the combined resistance is only slightly less than that of one rod, but if they are far enough apart, the combined resistance will approach one-half of that of one rod.

In a single circuit line of the usual design, with the conductors horizontally arranged (Figure 5), it works out well mechanically to place the ground wires above the tower legs or above the poles in a wooden H-frame arrangement, that is, on a vertical plane about midway between the two conductors. This has proved in practice to give good protection.

In the double circuit vertical arrangement (Figure 6), the ground wires are well coupled with the top conductors but are more remote from the middle and especially the bottom conductors, so that the coupling factor is rather low. To offset this loss of coupling factor, the ground wires should be spread farther apart. A good position in practice has been found to be about directly above the outermost conductors, which are usually the middle conductors.

The ground wires should be high enough above the conductors to avoid flashover between conductors and ground wires at midspan. However, if the ground wires are too high, the coupling with the conductors will be small and in case the tower voltage is raised above ground by lightning current in the tower, the voltage across the insulator string will be greater than it would have been with the ground wires closer to the conductors.

It has been found by experience that a height of approximately two-thirds the spacing between conductors for the horizontal arrangement and approximately equal to the spacing between conductors for the vertical arrangement is about right to give good coupling to the conductors, and at the same time avoid midspan flashover. Spacing C, Table IV, follows these criteria.

In regions where snow, ice, or sleet are likely to accumulate on the conductors, it happens occasionally on vertical arrangements (Figure 6) that the bottom conductor unloads its snow and ice and swings up level with or above the middle conductor. Also, in case of a coating of ice or sleet and a light wind in the proper direction, sometimes dancing or galloping occurs. In this case, the conductor swings in an oval loop (Lissajous figure). Lightning is not apt to be present under these conditions. Nevertheless, the spacing between conductors when in their closest position should be amply safe, so

Figure 2. Practice in the use of suspension insulators

Table I. Flashover of Suspension Insulators With 10-Inch Diameter and 5 3/4-Inch Spacing

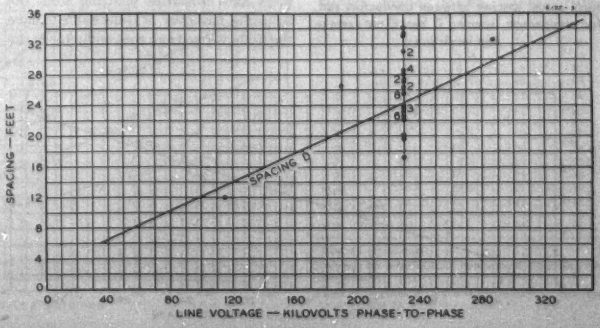
Barometer 30 Inches, Temperature 77 Degrees Fahrenheit, Vapor Pressure 0.6085 Inch

Number of Insulator Units	60 Cycles RMS		Impulse
	Dry Kv	Wet Kv*	Kv
1	80	50	125*-150
2	155	90	250*-255
3	215	130	355
4	270	170	440
5	325	215	525
6	380	255	610
7	435	295	695
8	485	335	780
9	540	375	860
10	590	415	945
11	640	455	1,025
12	690	490	1,105
13	735	525	1,185
14	785	565	1,265
15	830	600	1,345
16	875	630	1,425
17	920	660	1,505
18	965	690	1,585
19	1,010*	720	1,665
20	1,055*	750	1,745
21	1,100	780	1,825
22	1,145	810	1,905
23	1,190	840	1,985
24	1,235	870	2,065
25	1,280	900	2,145
26	1,325	930	2,225
27	1,380	960	2,305
28	1,410	990	2,385
29	1,460	1,020	2,465
30	1,505	1,050	2,550
31	1,550	1,080	2,630
32	1,600	1,110	2,715

From reference 7, except as otherwise noted. Impulse values based on 1.5x40 microseconds positive wave. Values for 21 units and more are extrapolated.

* From Locke Insulator Corporation catalog.

Figure 3. Horizontal arrangement of conductors; actual spacing between conductors and, for comparison, spacing D for average line insulation



that the dynamic voltage or overvoltages will not flash over. It should be noted in this case that the voltage between conductors is the line-to-line voltage. Spacing E equal to two-thirds A would have a dry 60-cycle flashover approximately 2.5 times the line-to-line voltage, while spacing E equal to A would have a 60-cycle dry flashover approximately 3.5 times the line-to-line voltage. In practice, spacing E may be as small as $0.5A$ for favorable snow and ice regions and up to $1.5A$ for regions where unloading of ice or snow or dancing of conductors may be expected.

Table IV gives the various spacings which co-ordinate with the different numbers of insulator disks, all based on $5^3/_4$-inch spacing between disks. In spacing D the width of the tower leg has been neglected. These values are plotted on Figure 7. If, for example, for a given transmission line seven disks are selected, then the spacings in Table IV corresponding to seven disks will co-ordinate with this number of disks. If for the same line it is desired to use nine disks, then all of the spacings should be increased to those corresponding to nine disks.

On Figure 3 are shown spacings D based on average line insulation from Figure 2, for comparison with the spacings found in practice for horizontal arrangement of conductors. On Figure 4 are shown spacings C based on average line insulation from Figure 2, for comparison with the spacings found in practice for vertical arrangement of conductors.

On lines with pin type insulators, there will be no swing of the conductors at the structure, so that spacing A could be used between conductor and down-lead as far as electric clearances are concerned. However, mechanical considerations may call for larger spacings, and spacing B would be applicable.

Figure 4. Vertical arrangement of conductors, actual spacing between conductors and, for comparison, spacing C based on average line insulation

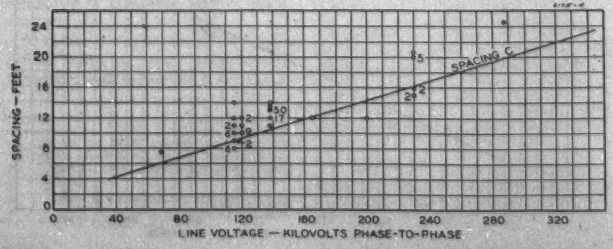


Table II. Flashover of Standard Rod Gaps

Barometer 30 Inches, Temperature 77 Degrees Fahrenheit, Vapor Pressure 0.6085 Inch

Gap Spacing, Inches	60 Cycles RMS Dry Kv	60 Cycles RMS Wet Kv*	Impulse Kv
1	22.5	—	38
2	40	—	60
3	50	—	75
4	58	—	91–95
5	66	—	106–114
6	74	—	128–141
7	—	—	141–155
8	89	—	159–166
9	—	—	175–178
10	105	80	190
15	150	125	275
20	200	170	350
30	295	255	505
40	385	345	650
50	480	430	800
60	575	515	945
70	665	600	1,095
80	755	675	1,240
90	835	755	1,385
100	910*	835	1,530
120	1,055	970	1,820
140	1,200	1,110	2,110
160	1,330	1,230	2,400
180	1,450	1,350	2,690
200	1,560	1,460	2,980

From reference 7, except as otherwise noted. Impulse values based on 1.5x40 microseconds positive wave. Values for spacing above 100 inches are extrapolated.

* From curve of Pittsfield General Engineering Laboratory.

Wood Pole Lines

Wood pole lines with hardware bonded and connected to grounded down-leads would be treated exactly the same as the steel tower lines previously discussed. If the hardware is not bonded, there will be a certain amount of wood insulation in circuit, and the impulse value of this wood when dry may be evaluated at 100 kv per foot, and when wet at 50 kv per foot.[8,9] For conservative design, 50 kv per foot or the equivalent of one-half disk insulator for each foot of wood may be used.

On account of the possibility of wood poles and crossarms splitting from the lightning flashover, it is desirable to have the flashover go from the conductor to the down-lead through air, rather than via the insulator string and crossarm or pole. If the impulse flashover through air is made about the same as the insulator flashover, the added insulation of the wood in series with the insulator will ensure that the flashover will take place through air to the down-lead.

Tower Footing Resistance

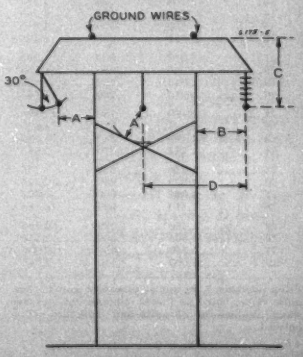
The selection of a particular insulation and co-ordinated spacing of conductors does not assure that the line will not flash over because of lightning. Flashover can only be prevented by

1. Shielding the conductors from direct strokes by properly placed overhead ground wires.

2. Low tower footing resistance so that the product of tower current and resistance will not exceed the flashover of the insulation and spacing selected.

Lightning currents to be expected may be determined from reference 10. Experience has shown that flashover usually will not take place if the product of tower current and footing resistance does not exceed the 1.5x40 positive flashover of the insulation or spacing to ground.[11] For example, on a line with seven insulator units having an impulse flashover of 695 kv, and assuming 100,000 amperes tower current, the footing resistance would have to be reduced to about seven ohms in order to prevent flashover. Reference 10 indicates a reduction in footing resistance during surges as compared with the tested resistance. This reduction is greater the larger the lightning current and the larger the normal resistance. The reduction may be considered as a factor of safety when figuring on possible

Figure 5. Single-circuit transmission line with horizontally arranged conductors



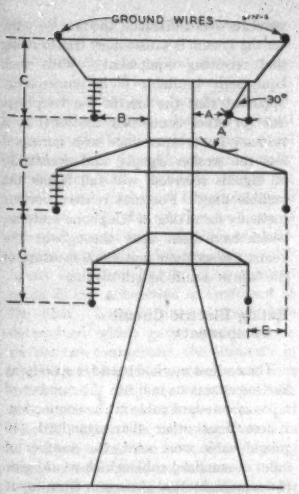


Figure 6. Double-circuit transmission line with vertically arranged conductors

flashover based on the normal resistance. Also, by neglecting the coupling factor an additional factor of safety is secured.

In some locations where the ground resistance is inherently high, it may be necessary to reduce the footing resistance by driven rods or counterpoise wires. Nevertheless, it may not be feasible or economical to obtain footing resistance values low enough. In these cases, it may be desirable to supplement the means already used with ground-fault neutralizers, expulsion protector tubes, or automatic high speed reclosing. These supplementary means have been described amply elsewhere.[12,13,14]

Table III. Minimum Number of Insulator Disks for Transmission Lines Based on 5¾-Inch Spacing

(1) Circuit Voltage Kv	(2) Number of Disks to Have 60-Cycle Wet Flashover Equal to or Greater Than: 3.5×L-N Voltage	(3) 4×L-N Voltage	(4) 4.5×L-N Voltage	(5) 5×L-N Voltage	(6) Average Practice Number of Disks	(7) Basic Impulse Level Kv
34.5	2	2	2	3	3	200
46	3	3	3	4	4	250
69	4	4	5	6	5	350
92	5	5	6	7	7	450
115	6	7	8	8	8	550
138	7	8	9	10	9	650
161	8	9	11	12	11	750
196	10	11	13	14	13	900
230	12	14	15	18	15	1,050
287	15	18	20	23	19	1,300
345	19	22	25	29	22	1,550

Conclusions

1. The 60-cycle wet flashover of line insulation should equal or exceed the voltages from faults and switching surges, that is, under the most advantageous conditions from 3 to 3.5 times normal line-to-neutral voltage, and under less favorable conditions up to 5 or 6 times normal line-to-neutral voltage. The impulse flashover should equal or exceed the basic impulse insulation level for apparatus.

2. The number of insulators having a wet 60-cycle flashover of 3.5 times line-to-neutral voltage is the minimum number which will meet the basic impulse insulation level.

3. Spacings between conductors, from conductors to tower, and from conductors to overhead ground wires should co-ordinate with the impulse flashover of the number of insulators chosen.

Spacing A from conductor to the nearest tower steel should have an impulse flashover about ten per cent greater than the insulator string flashover. In feet this is roughly equal to $\frac{\text{number of disks}+1}{2}$.

Spacing B, the horizontal distance from conductor to tower when the conductor is hanging vertically, equals $1.5A$.

Spacing C, between horizontal planes through conductors in the vertical arrangement, and between the plane of upper conductors and plane of ground wires, equals $2A$. The same spacing is used between the plane of conductors and plane of ground wires in the horizontal arrangement.

Spacing D, between conductors in the horizontal arrangement, is $3A$.

Spacing E, between vertical planes through middle and bottom conductors in vertical arrangement, varies from 0.5 to $1.5A$, depending on severity of snow and ice, and wind conditions.

4. Immunity from flashover depends not only on the insulation and spacings selected,

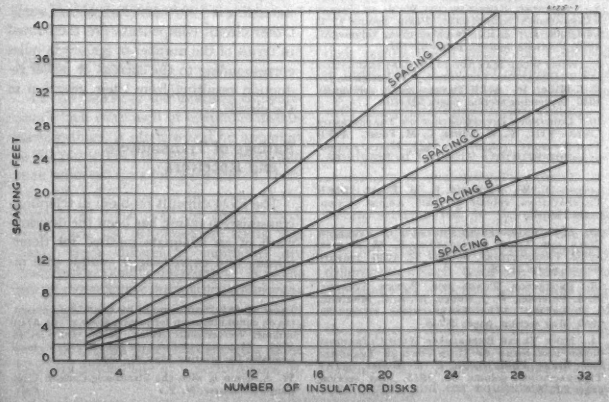


Figure 7. Relation between number of insulator disks and spacing for transmission lines:

A—Conductor to nearest tower steel
B—Conductor to vertical tower members
C—Between vertical conductors and between conductors and ground wires
D—Between horizontal conductors

Table IV. Co-ordination of Spacings With Number of Insulator Disks

Number of Insulator Disks*	Spacing A, Feet	Spacing B, Feet	Spacing C, Feet	Spacing D, Feet
3	2	3	4	6
5	3	4.5	6	9
7	4	6	8	12
9	5	7.5	10	15
11	6	9	12	18
13	7	10.5	14	21
15	8	12	16	24
17	9	13.5	18	27
19	10	15	20	30
21	11	16.5	22	33
23	12	18	24	36
25	13	19.5	26	39
27	14	21	28	42
29	15	22.5	30	45
31	16	24	32	48

* Spaced 5¾ inches.

Spacings for intermediate numbers of disks may be interpolated.

Refer to Figures 5 and 6 for location of spacings *A*, *B*, *C*, and *D*.

Transmission Rating of Telephone Systems

W. A. CODD
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Synopsis: The problem of rating the transmission performance of telephone connections is considered, including a review in considerable detail of a method proposed by J. R. Hughes.[1] With this background, a modification of Hughes' technique is presented with indications of certain attendant advantages.

A TELEPHONE, by definition, is a device for projecting the human voice beyond its normal range. There are other systems, of course, such as broadcasting, public address, paging, and recording-reproducing systems which perform this same general function. Each has its own type of service, the nature of which accounts for the differences in equipment and technique peculiar to each system. The service offered by the telephone system makes it the most complex of all. Each subscriber must have his own telephone set which must have access to all other subscribers individually for 2-way conversation and be able to establish and disengage all possible interconnections. The inherent complexity of establishing the transmission paths may tend to distract attention from the primary function of the system, which is to convey intelligence by means of the spoken word. Since this is the reason for the existence of a telephone system, there should be adequate means of measuring its success in accomplishing this end. This is important both to maintain adequate service and to point the way for progress in the art.

This paper will discuss the methods of rating which have been used from time to time throughout the course of development of telephone systems. Special attention will be given to a technique recently proposed by J. R. Hughes which will be reviewed in considerable detail. With this background, a presentation will be given of a modification of Hughes' technique with certain indicated advantages.

Since this discussion is concerned entirely with the transmission problem, the terms telephone system or connection are to be understood to refer to the equipment which makes up a complete voice transmission path from one subscriber to another.

Basis of Rating Methods

Inasmuch as the fundamental function of the telephone system involves the transmission of voice-produced electric currents over a distance, the first essential for the system is satisfactory transmitting and receiving equipment. With such equipment available it is immediately apparent that the loss in the telephone line (or other connecting medium) is of primary importance since with increased loss the weaker signals, and eventually all signals received, will fall below the audible limit. For that reason, various methods for rating of telephone systems, which have been used throughout the years, use as their unit some measure of the loss in a unit length of line.

Rating Electric Circuit Components

The earliest method used for specifying line losses was to indicate the number of miles of standard cable in the connection. Where lines other than standard (19 gauge) cable were used, the number of miles of standard cable which would give the same reduction of current from input to output at an average frequency of say 800 cycles per second would be the measure of the line loss. When dealing with such lines it was necessary to use some measure of current reduction in the line to determine the length of standard cable which gave equal loss. Accordingly, a further step in development was to state the line losses directly as a function of this current reduction. Thus, the 800-cycle mile was born. It is a unit based on the loss in passing through one mile of standard cable at 800 cycles per second, which is defined mathematically as the natural logarithm of the ratio of the input to output currents in one mile of standard cable (which is 0.109). Thus the formula for determining the number of 800-cycle miles corresponding to any values of input and output current on a properly terminated line is $2.30/0.109 \, [\log_{10} (I \text{ in}/I \text{ out})]$. Other circuit components are then rated in terms of the number of 800-cycle miles corresponding to the current or power reduction resulting from their insertion in the circuit.

Ratings of Transmitters and Receivers

The most difficult problem in telephone transmission rating has been the development of an adequate method for determining and expressing in simple and in-

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but on adequate shielding by overhead ground wires and sufficiently low tower footings resistance. In general, flashover will not be experienced if the footing resistance is less than the 1.5x40 microseconds positive impulse flashover of the insulation, divided by 100,000.

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formative terms the performance of transmitters and receivers.

Historically, the earliest attack on the problem is found in the volume or loudness tests. They were based on the fundamental assumption that two over-all connections which would produce equal loudness in the listener's ear were equally satisfactory and, therefore, would be given equal ratings. Observers were asked to judge the relative loudness of two such connections. A series of observations were made with successively different equivalent lengths of a standard trunk in one connection as compared to the other. When settings of trunk were determined which gave equal loudness for the two connections, the difference in equivalent length or attenuation was taken as the difference in rating of the two systems. Thus the performance of over-all connections, including the effects of various subscriber sets, was rated in terms of equivalent trunk losses.

Initially, the standard trunk used for such comparisons was the 19-gauge standard cable (referred to previously) and the ratings were expressed in terms of a number of miles of standard cable. It had the disadvantage of not producing uniform attenuation throughout the frequency range. Consequently, adjustments of the trunk changed not only the level but also the response-frequency characteristic by producing larger changes of attenuation at high frequencies than at low frequencies, thus making equality of loudness difficult to judge. It eventually was decided to replace the standard cable by a 600-ohm distortionless trunk. With the adoption of this trunk, the unit of line loss was replaced by a new unit of approximately the same magnitude, but defined as $10 \log_{10} (P \text{ in}/P \text{ out})$ and called at first the transmission unit (TU) and later the decibel (db).

Quality Differences

In the course of the loudness comparisons which were used in telephone instrument ratings, it often would be apparent to the observers that when the trunk had been adjusted for a loudness match, there was still a difference in the sound of the reproduced voice over the two systems, even when the distortionless trunk was used. Such differences commonly are described as quality differences. It seems evident that when the quality differences are large they so significantly may affect the intelligibility of speech transmitted over the system that volume rating alone becomes inadequate as a performance index.

Judgment Tests

Earliest attempts to take account of quality differences were the judgment tests. In these tests after the systems under comparison had been adjusted for equal volume, various observers were asked to listen to representative sentences transmitted over the system and give their judgment as to which system they preferred. The systems were rated according to the relative number of votes cast for each. A glaring weakness of the method is that the preferences expressed often may be quite unrelated to the actual transmission merits of the system and thus may be definitely misleading.

Articulation Testing

A much more fundamentally sound and informative method of evaluating the effects of quality differences is the articulation test. It has been used since before 1910[2] and its value still is recognized. The test is conducted in the following manner. Each of a number of callers speaks a list of meaningless monosyllables or "logatoms" over each of two systems to be compared. The logatoms preferably are inserted in sentences. A group of observers at the receiving end of the systems record the logatoms as they understand them. The percentage of sounds or logatoms correctly received is called the per cent articulation of the system. Per cent articulation is more significant than volume rating alone in that it does take account of quality differences as well as volume differences. A definite disadvantage, as compared to volume ratings, is that ratings of system components may not be simply combined to determine over-all ratings of connections of varied make-up. It is conceivable, however, that series of articulation tests may be taken on each system in such a manner that their results might finally be expressed in units suitable for this purpose. This will be discussed further in connection with immediate appreciation testing.

Analysis of Quality Differences

The existence of quality differences between systems led to development of other kinds of testing in which the specific objective was to explain the quality differences. Such tests are referred to commonly as objective tests, since they measure the physical characteristics of the system without dependence on the user's judgment or opinion. Their highest development is found in the use of artificial mouth and ear equipment.[3] They are very valuable tests for their intended purpose of analysis of performance. However, they do not afford a straightforward means for the rating of over-all performance in simple terms which are interpreted readily and hence need not receive further consideration here.

The Complete Rating Problem

The preceding discussions have called attention to the fact that one telephone connection may differ from another in the quality of the received speech as well as in volume or loudness. Quality differences may be either in frequency distortion (unsatisfactory balance of response throughout the voice frequency range) or in nonlinear distortion (the introduction by the circuit equipment of additional frequencies not present in the original speech). In addition to these effects, there are differences caused by the fact that the circuit is required to provide 2-way transmission with an invariable circuit, that is, without switching of transmitter and receiver alternately into the circuit for talking and listening, respectively. The result is the condition commonly described as side-tone, that is, a reproduction of a portion of the sound picked up by the transmitter of a given set in the receiver of the same set. During transmitting the presence of this side-tone causes the user to lower his voice, the amount depending on the amount of such side-tone. On receiving, side-tone introduces noise into the listener's receiver picked up from the room in which he is listening, the amount of such noise being dependent on the amount of room noise and the efficiency of the side-tone path.

It is evident that any figure of merit which is intended to serve as a measure of the over-all value of a telephone connection in conveying intelligence in actual service must be obtained in such a way as to include the effects of all of these characteristics of the equipment and their interactions on the users.

The Repetition Rate Test

The repetition rate test[4,5] was conceived and developed in the Bell Telephone System as a practical means of providing such a figure of merit. In this method, the test data are obtained by monitors on actual telephone connections of known make-up who make records of the number of times that the users, in the course of their conversatidns, give evidence of failure to understand each other. The monitors also observe the elapsed

time for each conversation. The data are summarized to give the number of repetitions required per unit time. This is called the repetition rate for the connection. Such data are statistical in nature and a large number of such observations must be made to give results of acceptable precision. Data are taken on a large number of different connections to cover the range of equipment types to be rated. The repetition rate is taken as the fundamental measure of the degree of success in carrying on conversations. Advantages of the volume rating system are retained by including in these tests measures of the variation of repetition rate with variation of length, or attenuation in decibels, of distortionless trunk included as part of the connection for this group of tests. It is then possible to convert variations of repetition rate caused by changes of any part or component of a telephone connection to equivalent changes in distortionless attenuation expressed in decibels. This gives a rating system in which the performance of any component of a connection may be stated in terms of the number of decibels of effective transmission loss as compared with the corresponding component of a standard reference system.

The basis of these ratings, the repetition rate test, has come to be generally regarded as the ultimate criterion of satisfactoriness of the over-all transmission path of a telephone connection. Disadvantages of this method are that it is essentially a field test, not adaptable to the laboratory, requires a very long time to obtain data, and is not generally practical for operating companies or manufacturers to use because of privacy requirements. The Bell System was able to overcome the latter difficulty by using several hundred stations in the American Telephone and Telegraph Company headquarters building and a like number at the Bell Telephone Laboratories.

The Immediate Appreciation Test

The immediate appreciation test[1] is an attempt to bring the repetition rate test into the laboratory. In other words, it is a proposed means of overcoming the disadvantages of the repetition rate test and still obtaining a rating which will include the effect of all the various system characteristics and the user's reactions to them.

In the application of the method, talking and listening crews speaking over the connection to be rated use lists of 20 sentences, each of about six to ten words, simple and straightforward in type, and extracted from the ordinary news columns

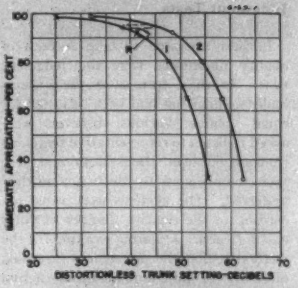

Figure 1. Immediate appreciation test—comparison of transmitting substations

Curve 1—Connection from transmitting substation *A* to receiving substation

Curve 2—Connection from transmitting substation *B* to receiving substation

of a daily newspaper. The listener is simply asked to decide whether or not he *appreciated* the meaning of each sentence *immediately* without any sort of delay or introspection on his part. On this basis he records each sentence as a success or failure. The percentage of successes is the percentage immediate appreciation and is taken as the criterion of performance of the system. It is this particular testing technique which distinguishes the test from other subjective tests. (These are tests which use talking and listening crews.) Other details which will be discussed have to do with means of taking account of the effect of service conditions (that is, speaker's volume level and room noise) and the means of presenting the data and converting it to more useful form.

Assuming the tests are so arranged as to take adequate account of service conditions, it will be seen that the outstanding difference from the repetition rate test is in the fact that the listeners also become observers in the test, so that the test data come directly from them instead of from monitors. The record, however, is based on fundamentally the same reaction, the difference being that the listener, as a result of a failure to appreciate the meaning of what has been transmitted, records this failure instead of requesting a repetition. Advantages are that the tests can be made in the laboratory, the required data can be obtained in a much shorter time since continuity of testing may be obtained, and the sensitivity of the method is higher, thus reducing the amount of required data and testing time. A possible disadvantage is a certain degree of artificiality, a fault of any laboratory test. In this respect, however, the immediate appreciation method has considerable advantage over the articulation test in which meaningless monosyllables constitute the matter transmitted. Here again there is a considerable advantage in time for the appreciation test since consistent results are found to be obtainable with much less matter transmitted. There is also the advantage of practically unlimited source of material in contrast to the limited number of logatoms available, thus reducing practice effects caused by familiarity with the material transmitted. The significant point, however, in the appreciation tests is the fact that the records obtained are intended to indicate specifically and directly the success of the telephone connection in conveying the meaning of connected words (that is, expression of thought) from talker to listener. Aside from these disadvantages of the articulation method, there appears to be no reason why the methods to be presented for rating of systems by application of the immediate appreciation technique might not use equally well the logatom articulation technique.

In the immediate appreciation tests, the direct result of a test run on two systems to be compared will show for the particular test conditions the per cent appreciation for each system. This, in itself, is a valuable indication of the relative performance of two systems. However, in order to enable expression of the results in more useful form, a number of runs are taken on each system, the amount of distortionless trunk in the connection being set at a new value for each run. Resultant data permit the plotting for each system of a curve of per cent appreciation as a function of trunk attenuation. Such curves are shown in Figure 1. Figure 2 shows by block diagram typical circuits which are used in obtaining these data. In Figure 1 the difference R of attenuation in decibels at a given level of per cent appreciation is taken as the difference in effective transmission of the two systems for the given test conditions. Thus, if this per cent appreciation is taken at a value which is agreed upon as representing a satisfactory standard of communication efficiency, it is indicated in the given example that 7.5 decibels more attenuation may be inserted in connection 2 than in connection 1, and still furnish transmission equal to the specified standard. It might be argued that 100-per-cent appreciation should be used. However, for practical reasons, a value somewhat short of this (95 per cent) is used. One reason is that the slope of the curves in this region allows the comparison to be made

more precisely; also, in general, it is not economical to design for perfection.

This method of interpretation of results assumes that it always will be possible to obtain a curve of the type shown in the figure for any system. A little consideration will show that it is a fundamental result of the test method. A difficulty, of course, would be presented by a system of such poor characteristics that 95-per-cent appreciation would be impossible to attain at any attenuation setting. However, there would be no practical interest in trying to rate such a system.

Treatment of Service Conditions

In his article on this method, J. R. Hughes gives extensive discussion of a statistical technique for taking account of the range of service conditions. The statistical method is based on frequencies of occurrence of various values of speaker's volume level and room noise determined from a large number of measurements of these quantities (in the case of room noise at actual subscriber locations). It consists of a procedure for weighting the observed data in accordance with these frequencies of occurrences. In making these tests the talker's volume level has to be treated in such a way that any tendency of the presence of side-tone, which he hears from his own receiver, to influence the loudness of his voice will be permitted to have its normal effect. This means that no artificial control should be exercised, such as the instruction to maintain a constant specified speaking level which is the common procedure in the usual voice-ear volume tests or articulation tests. In lieu of such control, the method of relating the speaking levels of the crew to the range of service distribution is by measurement of their natural speaking level; that is, the level at which they speak most naturally when conversing, without a telephone, in a quiet room.

In obtaining the data for application of this statistical technique, it is necessary to take several families of curves to give the required information on variation of per cent appreciation with service conditions. The several families are taken each for a different fixed value of room noise at the transmitting end of the connection, each curve in a given family being obtained for a different value of room noise at the listening end. Thus each individual curve of each family gives the variation of per cent appreciation with attenuation of distortionless trunk for a different combination of transmitting and receiving end room noises. About four families of four curves each are required. Variations of speaking level are taken as equivalent to variations of distortionless trunk setting.

By application of the statistical technique to these data, a single figure of merit is obtained which indicates how much more attenuation may be inserted in the better of two circuits and still obtain a grade of transmission at least equal to the accepted limiting value (95-per-cent appreciation) on the same percentage of all calls as on the poorer system.

A Modified Technique

In the foregoing discussions of immediate appreciation testing, interpretations of the test data have been made in terms of the excess amount of distortionless attenuation which must be inserted in the better of two systems in order to make the two systems equivalent in their ability to transmit intelligence. In the data discussed in connection with the statistical technique, this equivalence is established on the basis of an equal per cent of calls, enjoying at least 95-per-cent immediate appreciation; and the resultant rating is a composite figure dependent on all combinations (suitably weighted) of room noise levels and speaking levels occurring in service. In contrast to this, in standard Bell System effective ratings, the equivalence of two systems is established on the basis of equal success in conveying intelligence in the presence of a single representative (reference) value of

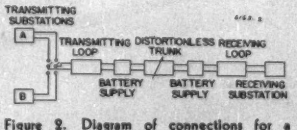

Figure 2. Diagram of connections for a typical immediate appreciation test

room noise existing at each end of the connection in each of the two systems. It seemed desirable in developing a laboratory test for rating telephone systems in this country to express the ratings on this basis.

The adoption of such a basis would result, also, in a very considerable reduction (to about 1/16) in the amount of test data required. This is true since it would mean that the data for determination of the several families of curves discussed in connection with the statistical technique would be reduced to that necessary to give a single curve for each system under test, such as 1 or 2 shown in Figure 1. The full extent of this simplification is not at once evident and may not be permissible always, since the technique employed still must take account of the service range of speaker's volume level, including the effects of side-tone characteristics of the transmitting subsets on this level. Accordingly, these tests must be conducted without instruction to the talkers to maintain any specified speaking level.

In general, it would be necessary to obtain a family of curves of per cent immediate appreciation as a function of distortionless trunk setting for each connection to be rated where the several curves of a family would be taken, each with a different crew having a different natural speaking level. The difference R (Figure 1) between the curves for two systems being compared would be taken for each crew. A weighted average value of R then would be obtained in which the weighting would be in accordance with the frequency of occurrence of the respective values of natural speaking level in service.

The ultimate simplification possible in the use of this method results by applying the fundamental assumption which provides the basis for Hughes' statistical technique. This is derived from his observation that under actual talking conditions amplitude distortion, even in systems using carbon transmitters, is negligible. The corollary to this is that changes in the amount of attenuation in the distortionless trunk may be taken as representing, also, changes of the speaker's volume level. Applying this assumption, for example, to the curves of Figure 1 leads to the following conclusions. Suppose that curves 1 and 2 and the resultant difference R between the two systems have been obtained with a crew having a given natural speaking level. Now suppose that this data were repeated with a crew having, for example, a 10-decibel higher natural speaking level. Application of the foregoing principle leads immediately to the prediction that the new curve 1′ (not shown) for the connection involving transmitting substation A will be obtained from curve 1 by adding ten decibels to the abscissa for each point, that is, the new curve will be displaced horizontally ten decibels to the right from curve 1. The new curve 2′ (not shown) for the connection using transmitting substation B will be obtained in an exactly similar manner from curve 2. Thus the difference R' between curves 1′ and 2′ will be identical to the difference R. Hence the difference R will be independent of the natural speaking level so that

only a single curve of per cent appreciation as a function of distortionless trunk setting need be taken for each connection to be rated.

When the assumption of equivalence of variations of attenuation of distortionless trunk and of speaker's volume level are not substantiated, the method of using several crews having different natural speaking levels should be adopted. This still would require only about one-fourth of the data required by Hughes' complete statistical technique and has the further advantage in this case of taking account of any existing amplitude distortion effects which are neglected by the fundamental assumption of the Hughes' method.

If ratings are desired for other room noise levels, they are obtained by repeating tests of the foregoing type with the room noise adjusted to the required level. As a simplifying approximation, such tests may be taken on a representative system, and the difference between the ratings for average room noise and the required room noise may be applied as a correction to the rating determined on any other system in question at the average (reference) room noise level.

Conclusion

The simpler form of the modified testing technique described has had some application in the rating of transmission performance of subscriber's sets. The limited amount of testing which has been done up to this time indicates this technique to be quite feasible. The immediate appreciation test in this general form, therefore, gives promise of being a very valuable tool in evaluating the overall merit of developments in telephone transmission equipment.

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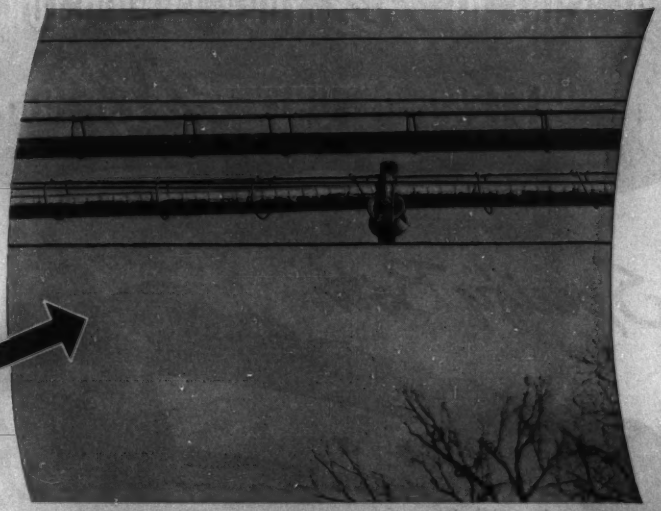

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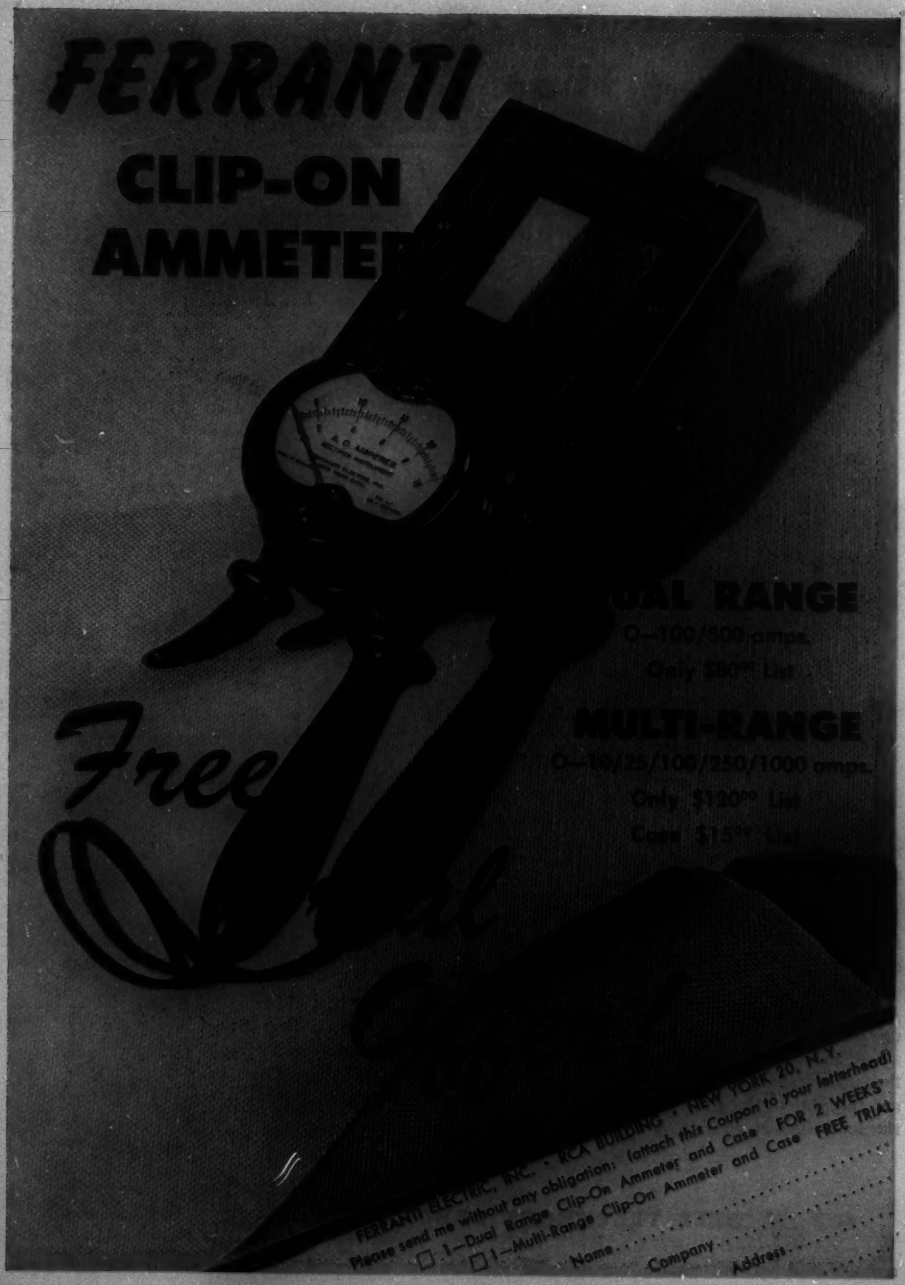
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With the new set, the telephone user can hear the operator more clearly, and she in turn hears better too—through the improved receiver and transmitter. Her voice enters the transmitter at an even level because, as she turns, the mouthpiece moves with her. Neckstrap and horn are eliminated. The whole thing weighs less than six ounces.

The new Bell System headset brings together the latest techniques in voice transmission and the ideas of the operators themselves — offering comfort, convenience, and electrical efficiency.

Out of new knowledge has come this novel head telephone fitted to the operator and designed to improve your telephone service.

BELL TELEPHONE LABORATORIES

EXPLORING AND INVENTING, DEVISING AND PERFECTING FOR CONTINUED IMPROVEMENTS AND ECONOMIES IN TELEPHONE SERVICE

Resonance is the Reason

behind "FRAHM" TACHOMETERS

For a complete description of Frahm Tachometers with list of types and ranges commonly supplied write for a copy of new Bulletin 1810-EE

HERE are two types of Frahm Tachometers—one permanently mounted, one portable—measuring the speed of a 60,000 kva turbo-generator. Although neither has any connection with the rotating element they are accurately indicating its speed—1800 rpm. How do they do it?

Resonance is the reason—the operating principle. Mere placement of the tachometer case in contact with almost any external part of the machine will cause the tuned reeds to pick up the minute vibratory impulses. The reed that is in tune with the machine's rotative speed will respond, the scale showing the speed in rpm. This principle and the method of indication are unique among speed-measuring instruments.

The simplicity of operation of the Frahm Resonant-Reed Tachometer is matched by its ease of installation and freedom from maintenance. There are no parts to wear, adjust, lubricate or renew. The instrument can be used in any position and gives years of trouble-free service. Various types (for rigid mounting or hand use) are available, in ranges from 900 to 100,000 rpm.

James G. **BIDDLE CO.**

ELECTRICAL & SCIENTIFIC INSTRUMENTS

1316 ARCH STREET • PHILADELPHIA 7, PENNA.

3 NEW TOOLS FOR PRODUCTION LINE OR LABORATORY

• SAVE TIME

• SAVE MONEY

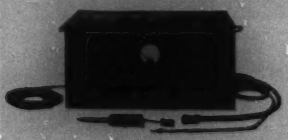
The newly-developed instruments shown on this page are already proving their value in scientific and industrial processing fields. Expert design assures simple installation, easy operation, and a minimum of maintenance. Fast and accurate performances result in time and cost savings. These tools solve newly-encountered problems and replace old tedious methods. Recently-found applications of these instruments are constantly simplifying testing procedures and improving production rates.

●Newly-discovered application—new G-E leak detector is being used in a test for leaks on a large transformer cover. This method is quicker and does not contaminate the oil as the old method using soap solution and air pressure did.

1. NEW LEAK DETECTOR DOES FASTER, BETTER JOB . . .

In the application shown, the G-E leak detector is being used to test studs on transformer plates for oil tightness. Contamination of material, which results from the method using air pressure and a soap solution, is avoided since helium, which is inert, is used as the tracer gas. The leak detector is a special mass spectrometer which locates leaks in closed systems—even small leaks in the presence of large ones. It is used to test leakage in radio tubes, refrigerator parts, boiler tanks, piping systems, and other closed systems which can be evacuated. For further information, write us.

2. ION GAGE MEASURES HIGH VACUUMS



With the G-E ion gage, the highest vacuums ordinarily encountered in factory or laboratory processes can be measured or monitored continuously. This instrument is used to measure high vacuum in process-control spectrometers, electronic-tube manufacture, vacuum-pump testing, and as a vacuum-failure relay. It measures pressures of 10^{-4} mm (0.1 micron) to 10^{-7} (0.0001 micron) of mercury. The ion gage circuits permit the indication of small pressure changes and the measurement of slow pressure drifts—without the inconvenience of continual adjustment. The gage tube filament is protected by automatic disconnection of the current at pressures above 10^{-4} mm. Write for Bulletin GEA-4529.

3. X-RAY PHOTOMETER FOR CHEMICAL ANALYSIS

Independent of the physical or chemical state of the material, the X-ray photometer indicates the concentration of one chemical element in the presence of others. Typical applications include the determination of the sulphur content of oil, the ash content of coal, and the halogenated hydrocarbon content of plastics. Built for continuous use, the X-ray photometer operates on the principle of X-ray absorption between sample and reference. Write for further information.

IN ADDITION, G-E BUILDS:

- Coil testers
- Coil-turn counter
- Core-loss test equipment
- Dew-point indicator
- Dew-point recorder
- Differential analyzers
- Pressure gages
- Thickness gages
- Thermal gas analyzer
- Insulation-resistance meter
- Luximeter
- Mass spectrometer
- Mercury-vapor detector
- Metal detectors
- Magnetic comparator
- Reflection meter
- Repeated-scrape abrasion tester
- Resistance comparator
- Schlieren equipment
- Sound-level meter
- Spectrophotometer
- Standard roughness specimens
- Tachometers
- Time-interval meter
- Vacuum gages
- Vibration-fatigue equipment
- Viscosimeter
- Winding-insulation tester
- Nuclear research equipment

The products listed are only a part of the complete line of measuring and testing tools offered by the General Electric Company. Our engineers are specialists in adapting these devices to your individual needs. For help and advice, call or write the G-E office nearest you. SPECIAL PRODUCTS DIVISION, APPARATUS DEPT., GENERAL ELECTRIC, SCHENECTADY 5, N.Y.

GENERAL ELECTRIC

HOW THE LAPP LINE POST FOILS FLASHOVER

The Lapp Line Post is a tall, one-piece porcelain body, without pin or other conductive material inside. It offers external air flashover distance as short as inside puncture path. And when an arc does go over it, it is much less vulnerable to damage than conventional insulators. Its short, sturdy petticoats are less affected by rapid heating from the arc, less likely to break. Even if the arc is severe enough to break away petticoats, their loss does not materially decrease flashover or leakage distance, and does not imperil the body. Injury to glaze from burning does not affect insulating value.

Engineers who first saw in the Lapp Line Post something "different-looking," after 15 years of Line Post service recognize that the difference in appearance is more than matched by a difference in performance.

WHAT HAPPENS WHEN FLASHOVER KNOCKS OFF A PETTICOAT?...

PIN-TYPE	SUSPENSION	LINE POST
FLASHOVER DISTANCE LOST 16%	FLASHOVER DISTANCE LOST 68%	FLASHOVER DISTANCE LOST 1%
LEAKAGE DISTANCE LOST 32%	LEAKAGE DISTANCE LOST 83%	LEAKAGE DISTANCE LOST 7%

Lapp

LAPP INSULATOR COMPANY, INC., LE ROY, NEW YORK

STACKPOLE

SINTERED **ALNICO II**

REAL ECONOMY
FOR SMALL SIZES
AND ODD SHAPES

. . . BETTER UNIFORMITY CHARACTERISTICS, GREATER MECHANICAL STRENGTH

*Licensed under G-E patents

Here is new help on permanent magnet problems—from one of the largest, oldest and most widely experienced producers of molded and sintered components in the industry.

Stackpole *Alnico II offers notable economy in the production of units up to two ounces. Odd shapes are a specialty. Engineering recommendations based on your requirements gladly submitted.

STACKPOLE CARBON COMPANY, ST. MARYS, PA.

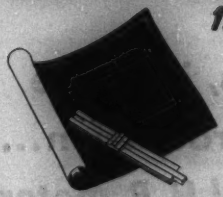
BRUSHES and CONTACTS (all carbon, graphite, metal and composition types)—IRON CORES—RARE METAL CONTACTS—RHEOSTAT PLATES AND DISCS—CHEMICAL CARBONS—WELDING AND BRAZING CARBONS—MOLDED PUMP and FLUID DRIVE SEALS—CARBON RHEOSTAT PILES—COIL FORMS, etc., etc.

MOLONEY *Power* TRANSFORMERS

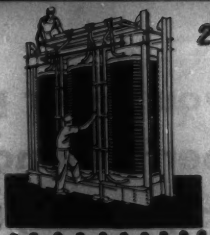
BEHIND EVERY STEP...50 YEARS OF EXCLUSIVE TRANSFORMER MANUFACTURE AND RESEARCH

Built to withstand severe operating conditions. High surge strength and thermal overload capacity. Moloney standard of design requires liberal use of basic materials assuring long life of trouble-free operation.

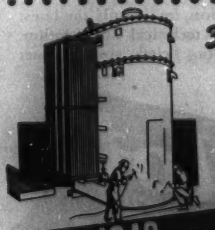
Bank of 21,000 KVA, 161,000 volt Power Transformers



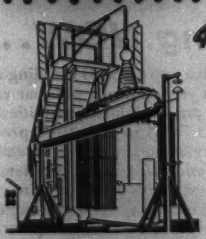
1. **Engineering research** is a vital part of the Moloney program of building transformers of advanced design. Fifty years of exclusive transformer manufacture have brought technical "know-how"... fifty years of engineering research have developed far-reaching improvements in design, processing, and fabrication. These are the factors which contribute to the trouble-free operation of Moloney Transformers.



2. **Core type construction** is standard on all Moloney Power Transformers... permitting maximum amount of winding surface exposed to the oil, for efficient dissipation of heat and reduction of hot spot temperatures. Circular windings provide greatest possible protection against distortion under the most severe operating conditions. Cores are of low-loss, silicon steel laminations properly annealed and carefully assembled.



3. **Tanks** are electrically welded, made of high-grade open-hearth steel especially suited for the purpose. These tanks are provided with rugged Z-bars or strong welded box type reinforcements. Bases are of heavy welded channel iron construction. Radiators are of all-welded construction, tubes are spaced for easy cleaning and painting, all welds are external, headers are designed so water cannot stand on surface.



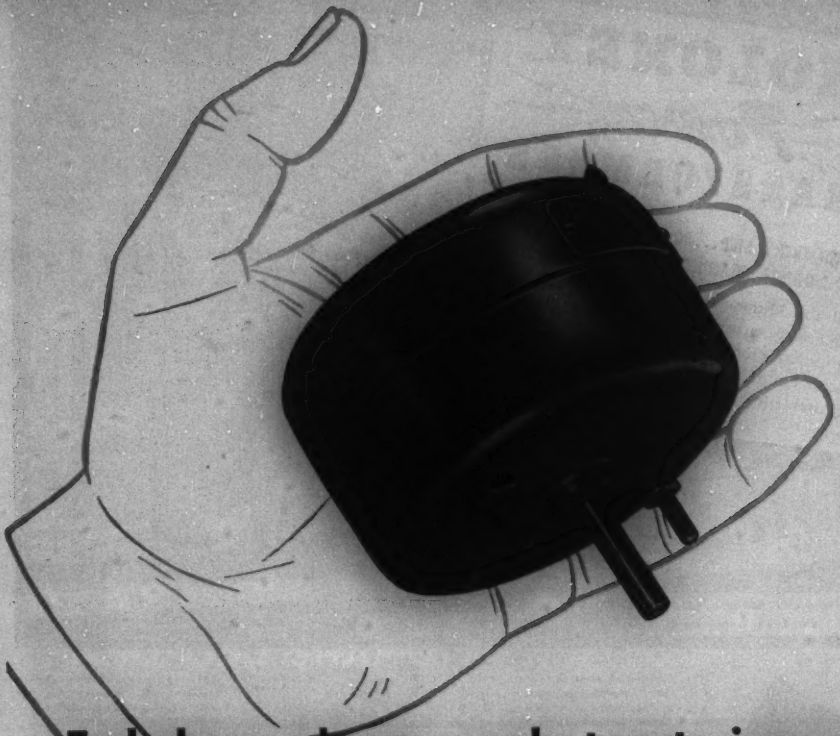
4. **Tested!** Besides numerous test boards for standard transformer tests, Moloney has complete facilities for making impulse tests. The Moloney 2,500,000 volt Surge Generator, with its recording cathode ray oscillograph, is available for impulse testing all ratings of transformers. Moloney Transformers are tested to meet the most rigid specifications for real "on-the-job" performance.

1896-1946..50 YEARS OF LEADERSHIP IN DESIGN, RESEARCH, ENGINEERING

MOLONEY ELECTRIC COMPANY

ST. LOUIS 20, MO.

POWER AND DISTRIBUTION TRANSFORMERS EXCLUSIVELY SINCE 1896



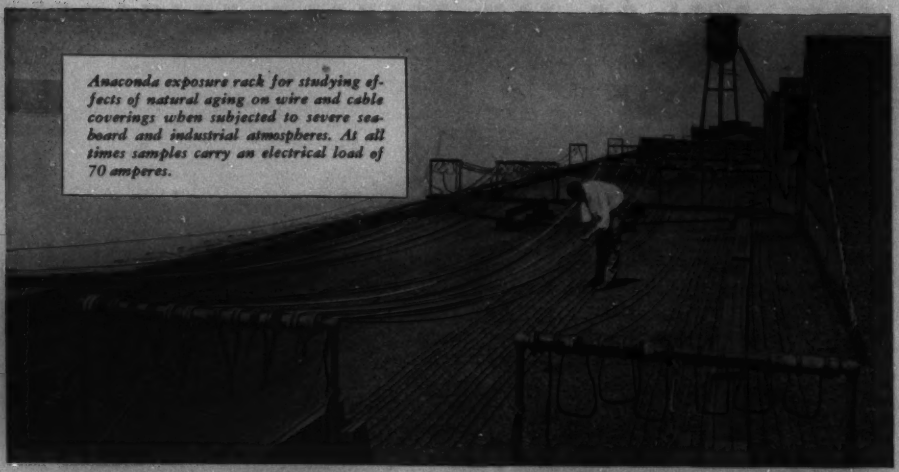
To help you lower product costs, improve product performance for 1947 production... *let us help you do your Fractional H. P. motor engineering NOW....*

You can take an effective step towards avoiding competitive disadvantages next year. Consult with our engineers *NOW* if you plan to use production-run quantities of small motors (1/500 to 1/15 H.P.) in your 1947 products. It will help ensure delivery of motors to your assembly lines on time. And your cost and performance problems will be solved during the earliest stages of planning to your best advantage. Our skilled, experienced factory engineer will meet with your engineers in your own plant. In answering your questions on small motor design, engineering and production, he'll apply the latest and most complete technical information. Write today, describing briefly your product design plans.

F. A. SMITH MANUFACTURING CO., INC.
450 DAVIS STREET ROCHESTER 2, N. Y.

FASCO

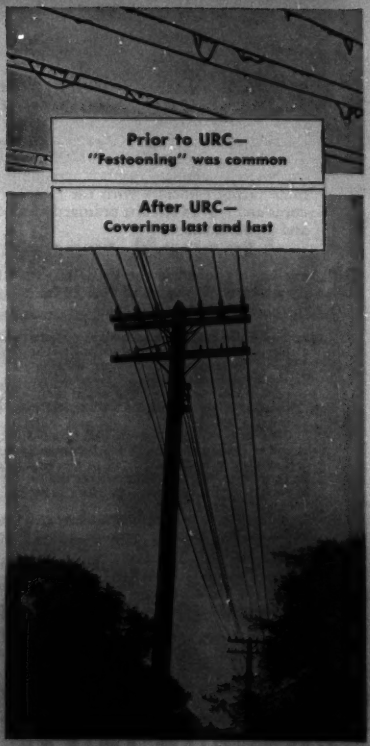
Pilot
Fractional H.P.
MOTORS & BLOWERS



Anaconda exposure rack for studying effects of natural aging on wire and cable coverings when subjected to severe seaboard and industrial atmospheres. At all times samples carry an electrical load of 70 amperes.

Rigid tests prove URC Weatherproof lasts and lasts...

Besides the severe tests applied to the components of Anaconda Weatherproof, the finished wire and cable is subjected to long natural aging tests as shown in the accompanying pictures. These exposures are supplemented by laboratory accelerated aging tests. Both types indicate a trouble-free service capacity for years and years.



ANACONDA

For Continuity of Service . . . Anaconda Triple Braid or Duraline URC

LOOK TO *Anaconda* FOR WEATHERPROOF THAT LASTS!

ANOTHER NEW VARIAC

FOR some time there has been a steady demand for an intermediate size VARIAC . . . something between the new Type V-5 (old Type 200-C) with a 5 ampere rated output, and the Type 100 rated at 18 amperes. The new Type V-10 has been designed to supply this need. Its rated output is 10 amperes, with a maximum of 15. This maximum rating coincides with the capacity of outlets, plugs, cords and No. 14 circuits ordinarily found in the laboratory and in the home.

The electrical and mechanical features . . . many of them exclusively found in the VARIAC, and all of them entirely new in the "V" types of VARIAC . . . are similar to those in the Type V-5, and include:—

1. New Unit Brush—brush, holder, pressure spring and current lead in one unit; removable in a second without any tools; when brush wears away, holder cannot short-circuit winding
2. Improved terminal plate with molded barriers between terminals to prevent short-circuits from strands of wire; both screw- and solder-type terminals; wiring diagram on terminal plate shows normal voltage between terminals
3. New strip-wound, silicon-steel core contributes to increased efficiency and to weight reduction of 25% below normal
4. Entirely new mechanical design of structural parts, mostly in aluminum
5. Double-pole line switch breaks both sides of the line
6. New, large output-voltage dial with additional calibration points and larger figures
7. A single screw, readily accessible under dial, loosens shaft for reversing dial and knob to change from table to panel mounting without affecting brush or stop settings

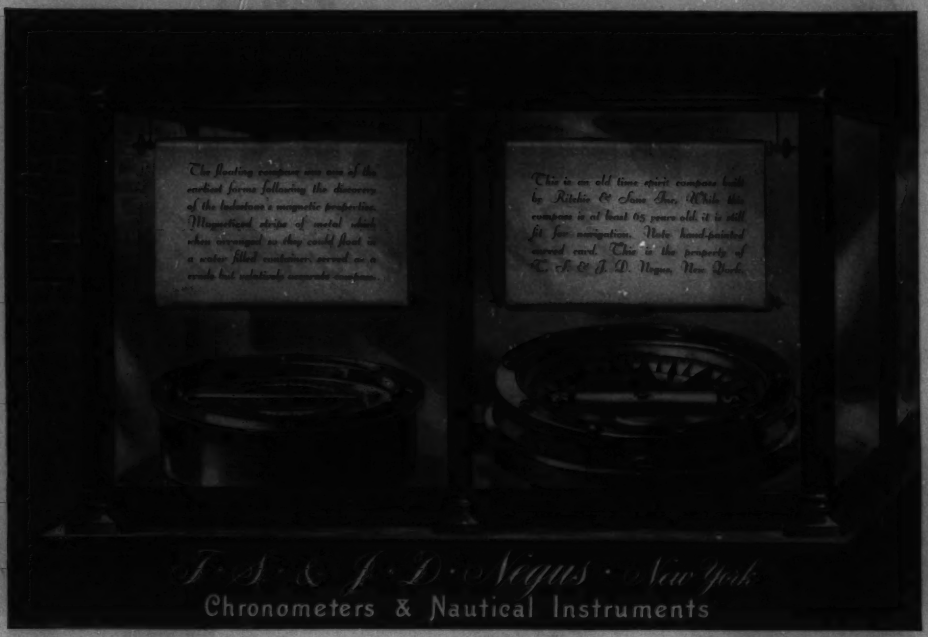
The Type V-10 VARIAC will be in production soon; deliveries are scheduled for November. Prices of the six models of the Type V-10 range between $27.50 and $35.50.

Write for a copy of the new VARIAC BULLETIN . . . it describes the V-10 and all other VARIACS

GR **GENERAL RADIO COMPANY** Cambridge 39, Massachusetts

90 West St., New York 6 920 S. Michigan Ave., Chicago 5 950 Highland Ave., Los Angeles 38

PERMANENT MAGNETS MAY DO IT BETTER!


The floating compass was one of the earliest forms following the discovery of the Indestone's magnetic properties. Magnetized strips of metal slightly elongated so they could float in a water filled container, served as a crude but relatively accurate compass.
This is an old time spirit compass built by Ritchie & Sons Inc., Which this compass is at least 65 years old, it is still fit for navigation. Note hand-painted curved card. This is the property of T. S. & J. D. Negus, New York.
T. S. & J. D. Negus · New York
Chronometers & Nautical Instruments

How Permanent IS A Permanent Magnet?

Since its discovery, the permanent magnet has been one of man's most faithful servants (as an aid in transportation and navigation). In most instances the life of the permanent magnet exceeds the life of the instrument it serves. After 65 years of faithful performance the Ritchie spirit compass, illustrated above, is still fit for navigation—the directing power of the permanent magnet is still accurate.

The permanent magnet used in the speedometer normally outlives the life of the automobile, despite the demagnetizing influences, physical strain, and vibration of high speed service. Although modern magnetic materials of greater retentive power have been developed, many of the antiquated permanent magnets are still serving adequately.

With the use of modern magnetic-alloy materials, infinitely more energy can now be packaged into permanent magnets. They are greater in strength . . . smaller in size . . . more functional in design . . . with greater stability in an electrical and steel age of vastly greater demagnetizing forces.

The Indiana Steel Products Company is a pioneer producer of "packaged energy", having made more than 24,000 applications in the 36 years of specialized permanent magnet production. Permanent magnets may have some application in your industry . . . may do some job or process better for you. Our engineers will gladly help you develop your plans for magnet application. For complete information and valuable technical data on magnet application and materials, please write for our "Permanent Magnet Manual."

★ **THE INDIANA STEEL PRODUCTS COMPANY** ★

PRODUCERS OF "PACKAGED ENERGY"
6 NORTH MICHIGAN AVENUE · CHICAGO 2, ILL.

SPECIALISTS IN PERMANENT MAGNETS SINCE 1910
PLANTS { VALPARAISO, INDIANA
STAMFORD, CONN. (CINAUDAGRAPH DIV.)

©1946 The Indiana Steel Products Company

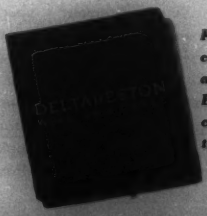
DELTABESTON*

Beats 'em All!

If there's a hot spot in your plant that threatens the power supply, Deltabeston can help you play safe. The unusual conditions met in steam tunnels, boiler rooms, steel plants, central stations . . . at furnaces, ladles, and soaking pits are tough on ordinary wire and cable. General Electric builds its Deltabeston cable to meet — and beat — these hazards.

There's a Deltabeston cable to protect against high ambient temperatures, another to take sudden temperature rises, many combinations in design and construction to maintain the safety factor you want. Or you may need a special cable, like the one illustrated, to meet an unusual set of conditions. This is one of many cables developed by General Electric engineers who are specialists in this field. They are ready to help in solving your wire and cable problems.

*Trade-mark Reg. U. S. Pat. Off.



For a copy of the complete Deltabeston catalog, write Section Y15-932, Appliance and Merchandise Department, General Electric Company, Bridgeport 2, Connecticut. Deltabeston Wires and Cables are distributed by G-E Merchandise Distributors.

GENERAL ELECTRIC

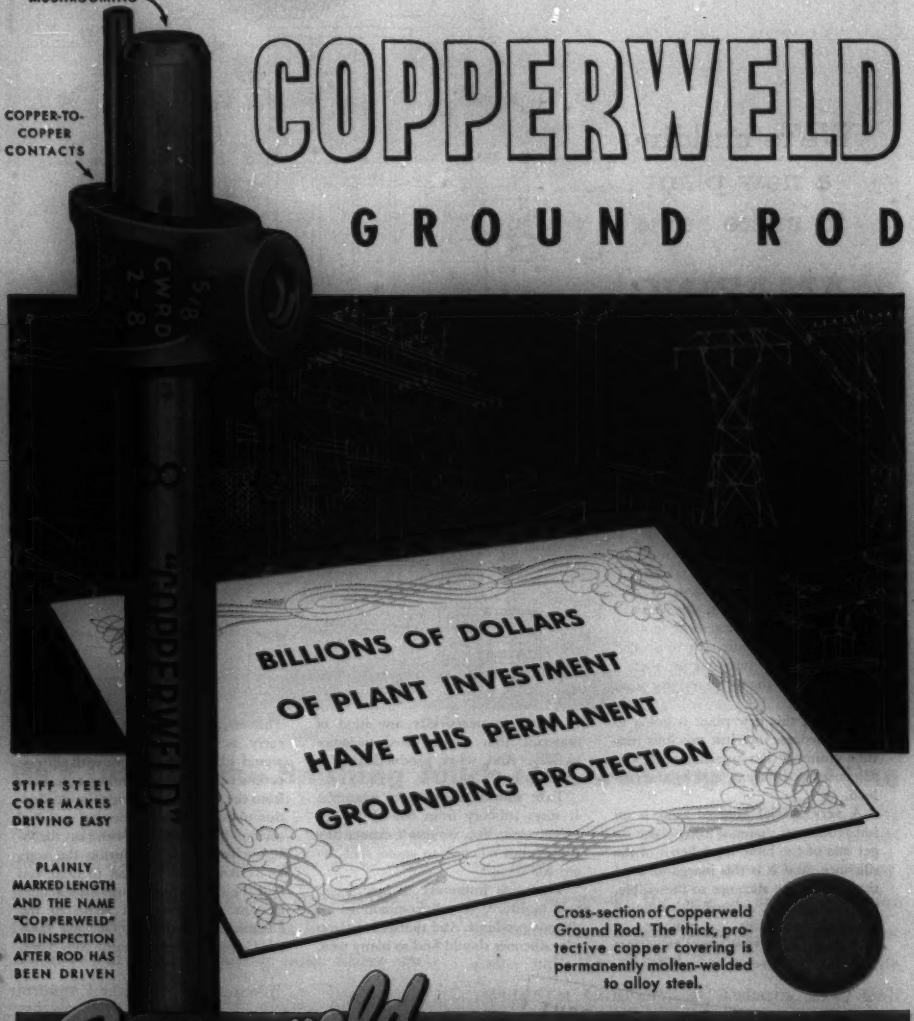
CHAMFERED END PREVENTS MUSHROOMING

COPPER-TO-COPPER CONTACTS

THE

COPPERWELD

GROUND ROD



STIFF STEEL CORE MAKES DRIVING EASY

PLAINLY MARKED LENGTH AND THE NAME "COPPERWELD" AID INSPECTION AFTER ROD HAS BEEN DRIVEN

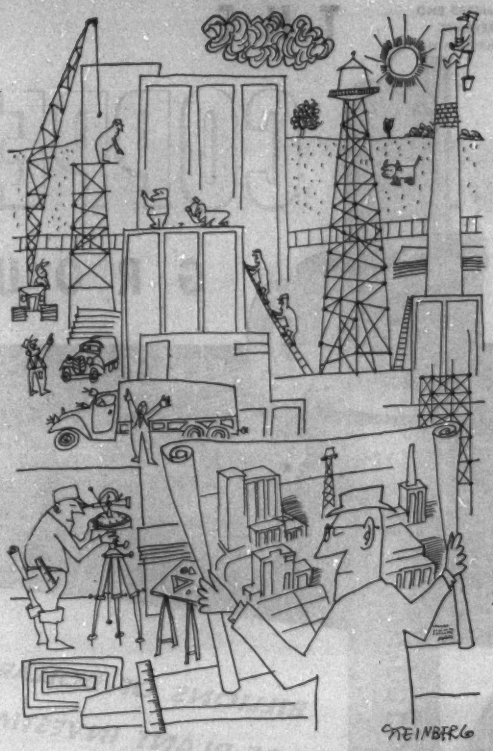
Cross-section of Copperweld Ground Rod. The thick, protective copper covering is permanently molten-welded to alloy steel.

Copperweld

Non-Rusting GROUND RODS and CLAMPS

National Sales Agents: HUBBARD AND COMPANY Pittsburgh, Pa.

We're building a new plant to make some AMAZING THINGS



If you happen to be driving upstate in New York—in the neighborhood of Waterford—one of these summer days, you'll get a chance to see a marvelous new plant we're building there.

You may not be impressed at all. You might say, "It's got brick walls . . . an ordinary-looking water tower . . . looks like a lot of other plants."

And you'd be right. But wait a minute. The big amazement is *inside* this new plant of ours. It's there that we are going to turn out products—and enough of them—to reshape a lot of things . . .

You see, this new plant is going to make silicones—not just precious test-tube grams of that amazing stuff—but silicones by the drum and by the carload.

A very special kind of sand is an important raw material from which we get one of the basic ingredients of the silicones. And it is this inorganic sand that makes the silicones so incredible. Oil . . . grease . . . electrical insulating materials . . . paint . . . rubber . . . plastics . . . DRI-FILM water repellents to apply to practically any kind of material that should shed moisture rapidly. And what products they're going to be!

Take silicone rubber, for example. It stays rubbery from 600° F to 60° below zero. You wouldn't expect any rubber but silicone to stand such an ordeal.

The same immunity to heat, cold, and moisture, too, is common to all silicone products. And that's the reason why silicones should find so many uses.

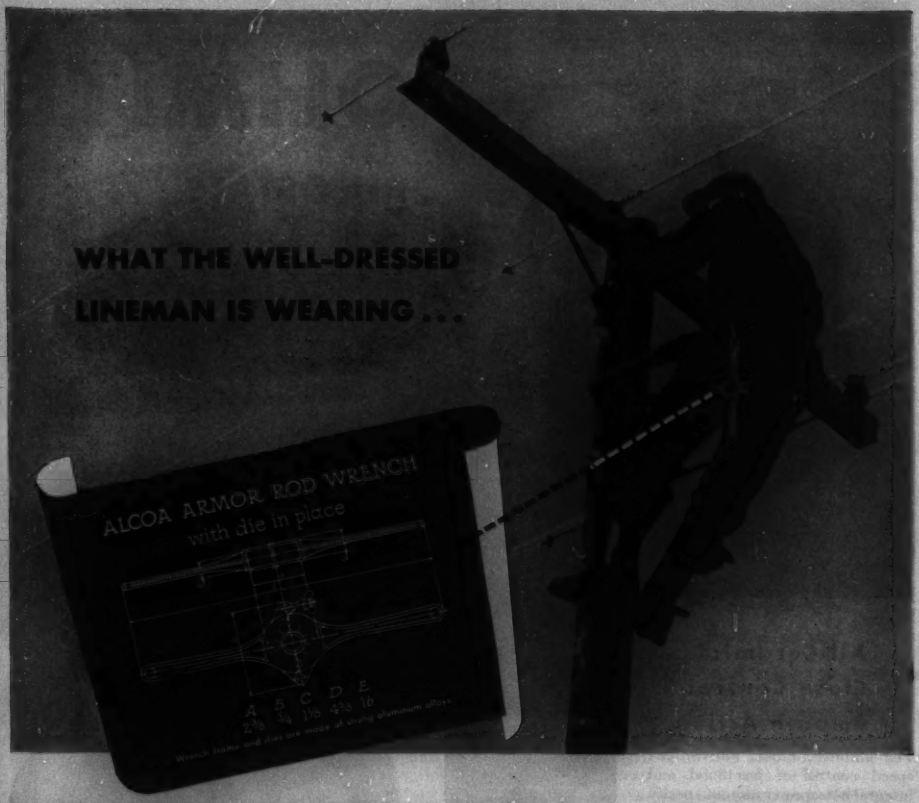
This new plant of ours will get rolling early next year. Meantime, if you would like to experiment with silicone products, you can get limited quantities from the General Electric pilot production plant—the same one that supplied silicone rubber for heat-resistant turbo-supercharger gaskets during the war. Of course, we'd be glad to help you find the most effective use for silicones in your business. Just write to the Chemical Department, General Electric Company, Schenectady, New York.

YOU'LL BE HEARING A LOT ABOUT

SILICONES

GENERAL ELECTRIC

CD-46-88



He's just put the finishing touch to a well-engineered line

Alcoa Aluminum Armor Rods reinforce conductors at points of support, preventing vibration failures. Armor rods also prevent chafing, take the brunt of flashovers at insulators, and are invaluable for repairing lines where such damage has already occurred.

Armor rods are evidence of careful, wise engineering. They pay off through lower operating costs.

For advice on the use of armor rods, for assistance in selecting Alcoa A.C.S.R. for your lines, call the nearby Alcoa office. Or write ALUMINUM COMPANY OF AMERICA, 2149 Gulf Building, Pittsburgh 19, Pennsylvania.

OHMITE

RHEOSTATS

for Motor Speed Control

All Ceramic Close Control Smooth Action

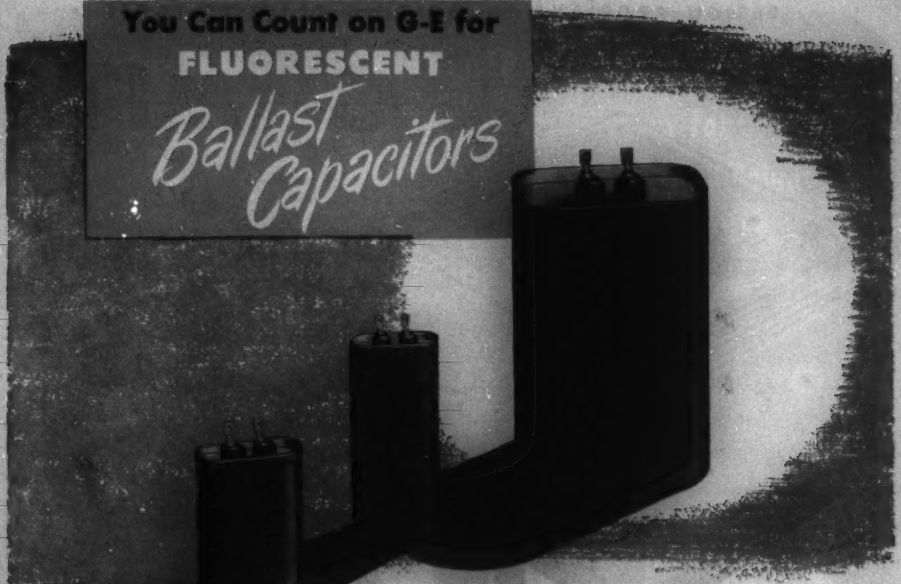
For smooth, close, convenient speed control of fractional and integral horsepower motors, specify Ohmite rheostats. All models have the distinctive, time-proven Ohmite features—all-ceramic construction, windings locked in vitreous enamel, and smooth-gliding metal-graphite brush.

The Ohmite line of standard rheostats is the most extensive available. Six wattage sizes in many resistance values are stocked for immediate shipment. Special resistance values, tapered windings, and tandem assemblies can be made to order. Consult Ohmite on your speed control problems.

Write on Company Letterhead for Catalog and Engineering Manual No. 40.

OHMITE MANUFACTURING CO.
4801 Flournoy St., Chicago 44, U. S. A.

You Can Count on G-E for FLUORESCENT *Ballast Capacitors*



- **New Plant Capacity Assures Steady Supply**
- **Full Range of Ratings to Meet All Design Needs**
- **Long Design Experience Cuts Field Rejects to the Bone**

FOR STEADY SUPPLY—General Electric ballast capacitors are produced at two large General Electric plants—at Fort Edward, N. Y. and at Pittsfield, Mass. They are a continuous-production product, manufactured in plants which have facilities for taking care of both present and expanded future business. *Count on General Electric as a reliable source of supply.*

FOR FULL RANGE OF RATINGS, SHAPES, SIZES—The use of *Pyranol insulating liquid assures compact size. This, with a full range of ratings, and a full line of container shapes for every application, permits you to *count on G-E ballast capacitors for complete manufacturing flexibility.*

FOR HIGH QUALITY THAT CUTS BALLAST REJECTS—General Electric's long experience in designing and manufacturing not only ballast capacitors, but other types of capacitors as well, is an assurance of high quality. There are millions of G-E Pyranol capacitors establishing excellent service records in all types of applications. One reason for this is that General Electric "goes to extremes" in subjecting capacitors to the most rigid inspection and quality control. From the initial selection and manufacture of basic materials, through each manufacturing operation, and throughout the most exacting inspection and tests, G-E capacitors are subject to constant laboratory supervision. *You will find that it pays to count on G.E. for quality ballast capacitors.*

FEATURES OF G-E BALLAST CAPACITORS:

1. **Pyranol** assures extreme stability at the high ambient operating temperatures of fluorescent ballasts.
2. **Pyranol** impregnation assures longer life.
3. **Pyranol** dielectric assures small size.
4. **Pyranol** is non-inflammable.

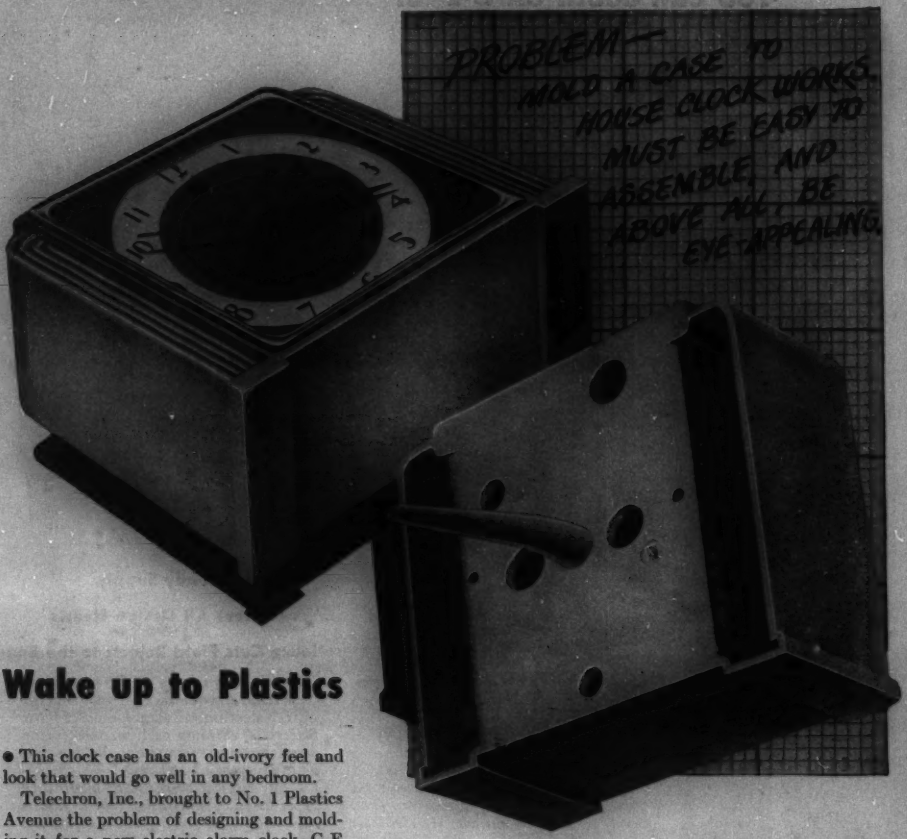
**Pyranol is a non-inflammable liquid dielectric with closely controlled characteristics, developed by General Electric and used in G-E Capacitors for over 15 years.*

GENERAL ELECTRIC

GENERAL ELECTRIC COMPANY
Apparatus Department, Sec. D407-109
Schenectady 5, New York

Gentlemen: Kindly send me further information on G-E Ballast Capacitors.

Name .....
Company .....
Address ..... City ..... State .....

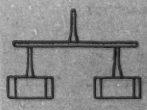


Wake up to Plastics

● This clock case has an old-ivory feel and look that would go well in any bedroom.

Telechron, Inc., brought to No. 1 Plastics Avenue the problem of designing and molding it for a new electric alarm clock. G-E engineers recommended injection-molding G-E Compound 1403 for these reasons:

1. This material is a thermoplastic polystyrene adaptable to economical injection-molding.
2. It is available in an attractive ivory tint—and a wide range of other colors.
3. It fulfills all of the electrical and mechanical requirements of a modern electric alarm clock case.



UNIQUE MOLD DESIGN FOR TELECHRON

The two-cavity injection-type mold for the clock case is unique in that it has one main sprue and two secondary sprues. The sprues are that part of plastic material formed in the channels through which the liquid thermoplastic is forced into the clock case cavities.

G-E plastics engineering provides Telechron with more production per cavity; less chipping and breakage during manufacture and shipping. And now Telechron is getting better-looking clock cases than ever before for about one-third the cost formerly paid.

This is just another case to point up the advantages of consulting General Electric—the world's largest manufacturer of finished plastics products—on any plastics design or production problem. *"Designing Molded Plastics Parts," a helpful handbook, will be sent promptly to you upon request.* Write Section E-10, Plastics Divisions, Chemical Department, General Electric Company, 1 Plastics Avenue, Pittsfield, Massachusetts.

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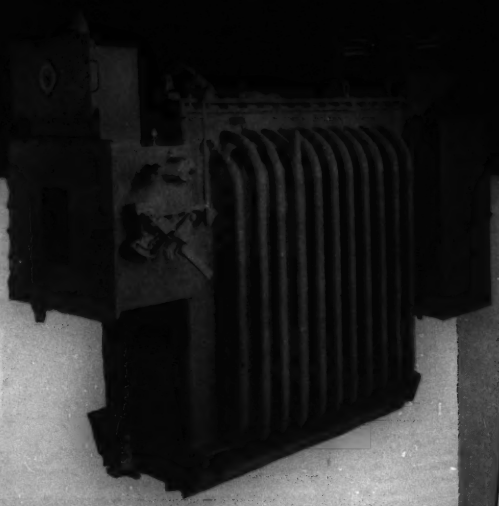

AmerTran Abestol Transformers meet the full requirements of the National Electrical Code. They do not require fireproof enclosing vaults. Since there are no installation restrictions, they can be installed as close to the center of load as desired.

- **Non-Inflammable**
- **Require no vaults**
- **Save installation space**
- **Reduce copper costs— locate at load center**
- **High efficiency**

ABESTOL, the non-inflammable AmerTran liquid used in these transformers, has high dielectric strength and efficient cooling properties. It does not generate inflammable gases.

Abestol Transformers are particularly suited to locations where the hazard of fire must be avoided. At the same time they afford other distinct advantages. Installation usually is simpler and less expensive than that required for oil-filled types. They can be installed indoors or outdoors, on platforms, directly at the load center. They make possible substantial savings in length and cost of secondary lines.

Abestol Transformers can be supplied for power and distribution service in all practicable ratings and ratios. Write for further information.

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headquarters for bonded varnished SLOT insulations!

Irv-O-Slot provides the electrical protection necessary for top-quality slot insulation. Moreover, it possesses the mechanical strength required to withstand punishment received during motor assembly and operation. A complete range of varnished fabrics duplexed to selected rag and fish papers allows wide selection. All the base fabrics secure their high dielectric strength from uniform coatings of Irvington-formulated insulating varnishes.

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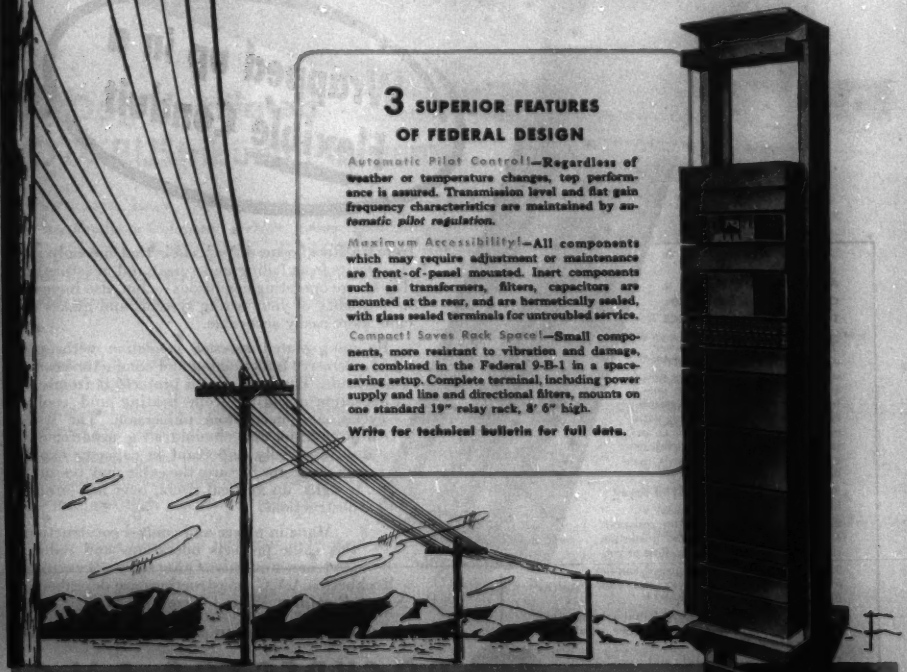

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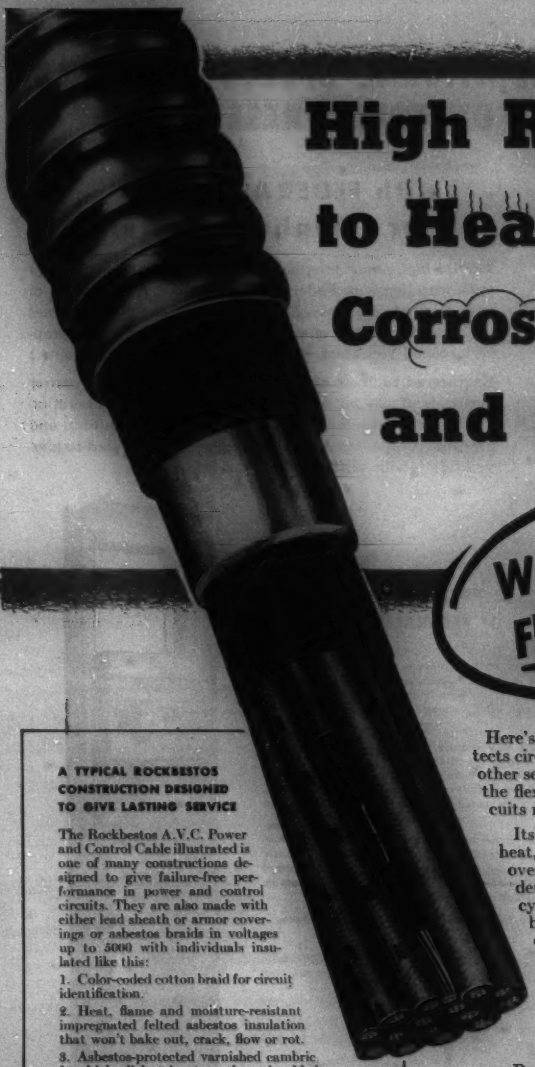

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DOUBLY PROTECTED ... from accidental grounding or shorting

MECHANICALLY
Rigid casing of expanded metal welded to heavy gauge side channels keeps large solid objects away.
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Bus bars, which are supported by porcelain insulators, are machine wrapped with Natvar seamless bias varnished cambric tape. This serves as a protection against small objects which might enter the ventilated duct casing and short circuit the bus bars. Also, the tape insures maintenance men and electricians against accidental contact with current carrying bus bars.

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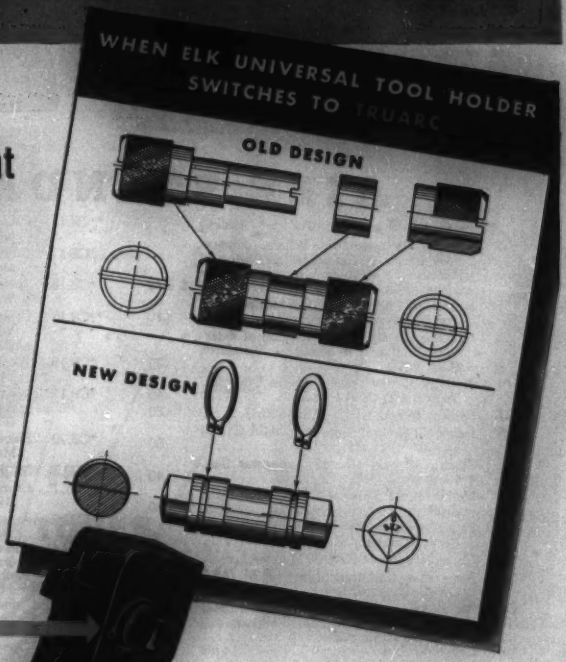

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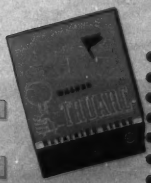

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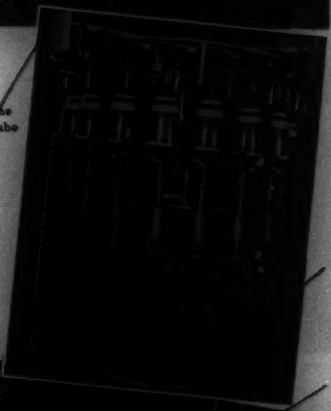

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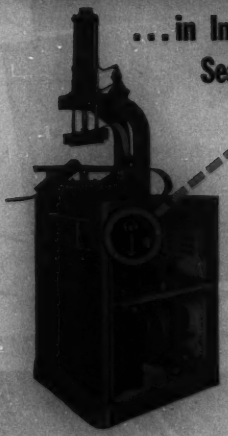

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Filament Current	27.5 amp.
Maximum Ratings for Maximum Frequency of 50 Mc	
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DC Plate Current	1.25 amp.
Plate Dissipation	2500 watts
Overall Height	App. 7 inches
Maximum Diameter	3½ inches
Type of cooling	Forced Air

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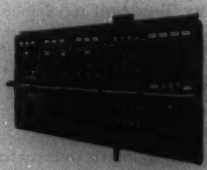

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With brushes, too, the kind of contact importantly effects results.
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Coors insulators being assembled in rectifier units.
Battery of twenty-four 12-tank Allis-Chalmers Excitron Assemblies supplying power to two Aluminum reduction circuits; high-speed anode breakers on left, cathode breakers on right.
COORS PORCELAIN COMPANY
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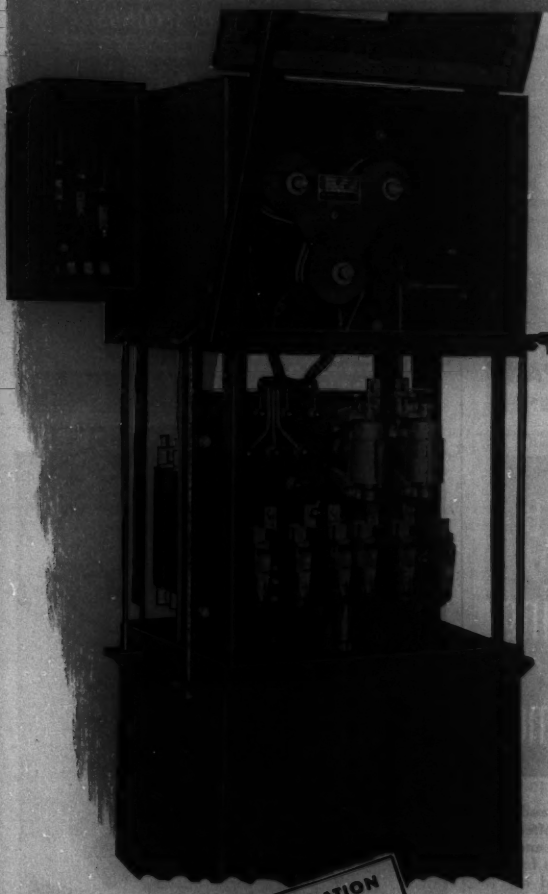
Give your squirrel-cage induction motors a

Smo-o-oth Start



with a ROWAN
OIL IMMERSED
IMPEDANCE STARTER
(Type 900 Series)

This Rowan push button operated, fully automatic, reduced voltage starter of the impedance type, assures smooth starting with a minimum of line disturbance. It is a starter of the closed transition type utilizing for its acceleration, a combination of current and time. The acceleration period is dependent solely upon the driven equipment and load—thereby completely eliminating the human element. Continuous wound impedance coil assures freedom from tap failures—impedance is adjustable to each application. The unit is equipped with magnetic overload relays with automatic reset, providing a combination of inverse time element and instantaneous operation and single phase protection. Short circuit protection is afforded by time-tested Rowan Air-Seal fuses. It has a sealed-off, centralized wiring compartment for load line and control leads and provision for straight thru conduits. Enclosure is of the weather-resistant, dust-tight type. All electrical operating parts are oil immersed and the tank is mechanically interlocked to prevent lowering of the tank when the safety switch is in the "ON" position, or closing the switch when the tank is lowered.

Illustrated circular containing complete details is available upon request.

TYPE 900 KBF COMBINATION
Reduced Voltage Starter of the Impedance Type for use on 3 ph., 600 V service or less. Also available in 950 series for 2300 V., 3 ph., service.

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Fast, easy-to-read, and versatile, the compact *-hp-* 400A Vacuum Tube Voltmeter accurately handles voltages at frequencies ranging from 10 cps to 1 megacycle. There are no troublesome adjustments to make during measurements. And normally no precautions against overloads are necessary.

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PROVIDE DELAYS RANGING FROM 1 TO 120 SECONDS

Other important features include:

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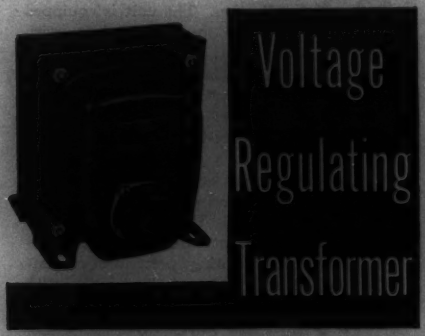

Regulating the voltage for the control of speed, heat, or light, of an electrical appliance is often desirable. The series 141 transformer, with end bells, provides a primary tap changer on front for manual voltage adjustment. Can be supplied to your electrical specifications in sizes ranging from 35 VA to 500 VA.

Further details in Bulletin 148.

ACME ELECTRIC CORPORATION
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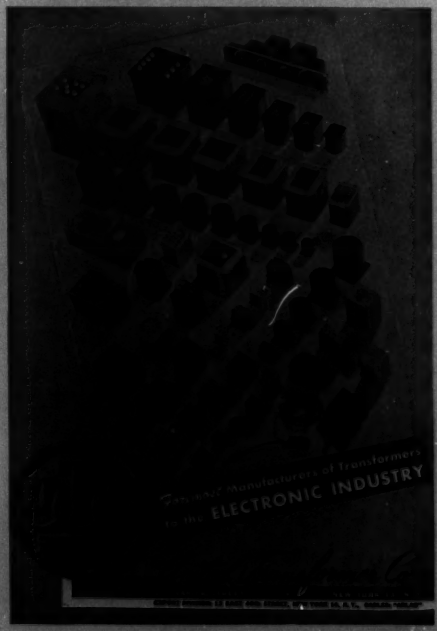
Acme Electric



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. . . Low Residual Inductance
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Mica Capacitors

Dimensions: 2¾" w. x 2¼" d., x 1¾" h.

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● The *brand new* Aerovox Series 1690 molded-in-bakelite mica capacitor is intended specifically for circuits where inductance must be kept at a minimum. It is designed for least possible residual inductance, low r. f. losses and lower r. f. resistance and impedance. What's more, it provides increased KVA ratings for given capacitor sizes.

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Exceptional compactness for given KVA ratings; exceptionally-low-loss operation; ability to withstand constant duty and heavy overloads—for these and other reasons this latest Aerovox development marks a new performance standard for severe-service capacitors.

● *Interested?* Write for detailed information. Meanwhile, submit that capacitor problem for our engineering collaboration.

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IF YOU make any of the above products, you should be interested in finding out how *better permanent magnets* can improve efficiency and reduce costs. Put your design, development or production problems up to The Arnold Engineering Company. Arnold engineers have been of great assistance to many manufacturers and are at your service to advise exactly what Alnico permanent magnet will solve your particular problem.

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Save . . .

on the unit cost . . . speed production . . . avoid costly delays in delivery

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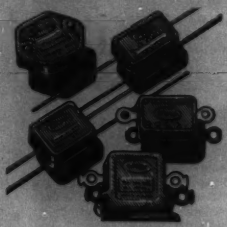
WAA SURPLUS CAPACITORS



All types, all sizes, in whatever quantity you need.

The enormous WAA supply of surplus capacitors offers an opportunity to solve capacitor shortages and at the same time gain a saving on the unit cost. The stock includes products of all the leading manufacturers. The component you need is almost certainly available from this vast WAA supply—probably even the very same manufacturer's item you are now using.

Quality of WAA surplus capacitors is assured by government inspection to rigid Army and Navy specifications established for military use—equal or superior to commercial standards.

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Recently we had an illustration of how much self-supporting aerial cables save over open wire. One of our customers planned to put in a 13 k.v. open wire feeder. In order to get it installed it would have been necessary to go around a town which would have taken 16 miles of open wires. By changing the specifications to Simplex self-supporting aerial cable it was found possible to do the same job with only 2½ miles of line. The saving in this case amounted to a good many thousand dollars because the poles, cross-arms, pins, insulators, line hardware, etc., that were necessary for the 16-mile line did not have to be bought and installed. Instead, the 13 k.v. line, because it was insulated, was suspended from existing pole lines.

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It's a certainty that you can save money for your company by reducing the variations in brush specifications and by streamlining your brush orders and inventories. National Carbon Co., Inc., is ready to assist you in taking advantage of this program. Simply get in touch with our nearest Division Office today. Dept. EE.

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—with NO Moving Parts

Just connect the three permanent leads, in any order, to the circuit under test and the phase sequence is quickly and simply determined. No combination of leads from various binding posts to arrange—no loose leads to become lost.

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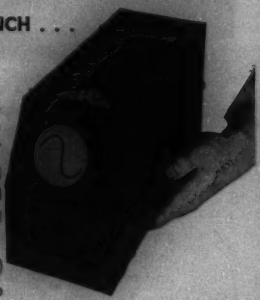

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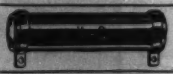

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THEIR USE IN ELECTRONIC CIRCUITS

by M. BROTHERTON, Ph.D.
Bell Telephone Laboratories, Inc.

This book is based upon seventeen years' experience in the largest industrial electronic laboratory on earth—the Bell Telephone Laboratories. It presents in streamlined form all the important existing data on capacitors—types, dimensions, characteristics, and how to choose and use capacitors for electronic circuits.

It tells the circuit designer the important elements he must understand and consider in transforming capacitance from a circuit symbol into a practical item of apparatus, capable of meeting today's operation requirements. The book is well organized, numerous diagrams are included, and all the data is arranged and summarized in convenient tables and charts for fingertip reference.

It tells you in detail:

- How to make best use of capacitors in electronic circuits
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- Twenty questions to the right capacitor

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EL. EC. ENG.—OCT. '46

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... Directed to those who manufacture electronic equipment that must be **MOISTURE PROOF** *and/or* **FAILURE PROOF**

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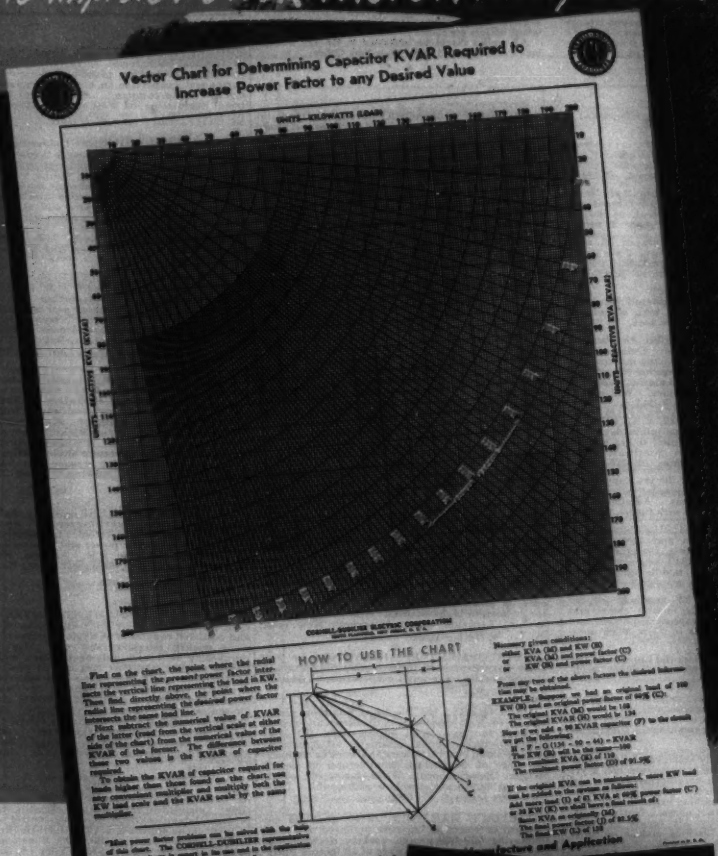
How To Determine Capacitor Kvar Required To Improve POWER-FACTOR To Any Desired Value


Vector Chart for Determining Capacitor KVAR Required to Increase Power Factor to any Desired Value
UNITS—KILOWATTS (LOAD)
UNITS—REACTIVE KVA (KVAR)
UNITS—REACTIVE KVA (KVAR)
CORNELL-DUBILIER ELECTRIC CORPORATION
HOW TO USE THE CHART
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WANTED: Substation Design Engineer by Utility in Florida. Must have considerable experience with utility having extensive transmission system. Must be able to handle sub-station estimating and planning and direct draftsmen from one line diagram through construction drawings. Not temporary. State age, education, experience, references, salary requirements and when available. Address, Box 404, Electrical Engineering, 33 West 39th St., New York 18, N. Y.

WANTED—ELECTRICAL TRANSMISSION ENGINEER. Experienced graduate engineer, capable complete design of high voltage transmission lines, including lightning protection, economic selection of voltage, conductors and structures, and preparation of estimates of cost, specifications and plans for installation. Qualifications and experience record should be submitted with letter of application. Address, Box 405, Electrical Engineering, 33 West 39th St., New York 18, N. Y.

(continued on page 54)

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(continued from page 52)

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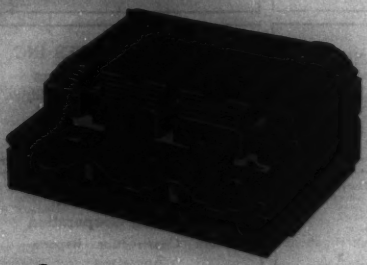
WANTED—ELECTRICAL PROJECT ENGINEER. One (1) experienced graduate engineer, responsible charge electrical engineering and design of steam-electric and hydro-electric power plants and high voltage substations. Applicants please furnish personal data and experience record. Box 122, Church St. Station P. O. New York 6, N. Y.

INDUSTRIAL ELECTRICAL ENGINEERS: For design work in chemical plant. Technical graduates with minimum of two years experience in layout and design of industrial power generation, distribution, application, control, conversion. Permanent position with large chemical company in the Southwest. Salary commensurate with ability and experience. Give complete details of past experience, education, etc. Application by letter or conference. Address, Personnel Director, THE DOW CHEMICAL COMPANY, Freeport, Texas.

WANTED—UNDERGROUND ENGINEER—Graduate electrical engineer, with at least eight (8) years' experience in design of underground distribution and transmission systems. Applicants should be capable of selecting most suitable types of insulations and coverings for underground cables. Experience with underground and submarine cables above 33 kv desirable. Please furnish experience record and personal data with application. Address, Box 406, Electrical Engineering, 33 West 39th St., New York 18, N. Y.



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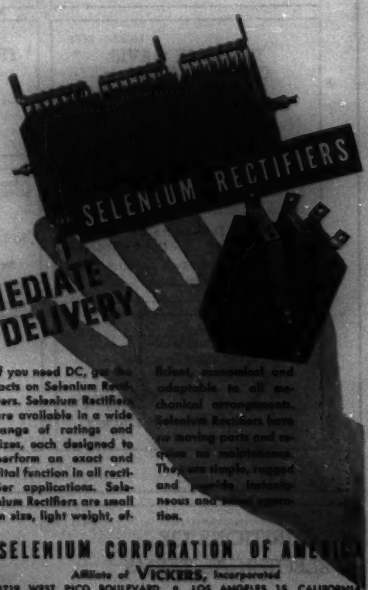

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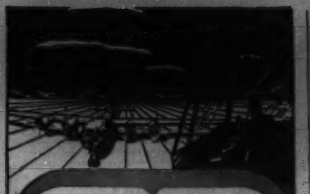

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Silicone News

DC

Is DC 996 the key to the market for air cooled transformers?

When transformer coils look like this after 6 months of service, there is a place for heat-resistant Silicone insulation in air-cooled transformers. Certainly an eager market awaits a serviceable, lightweight transformer. Electrical engineers are now working to supply that market with transformers insulated with inorganic materials impregnated with DC 996.

The added heat resistance of DC 996 offers a potential reduction of 30% to 50% in size and weight compared with other air-cooled transformers and up to 75% reduction compared with oil-filled transformers of equal capacity. Increased reliability due to the greater moisture-proofness, thermal stability, and chemical resistance of DC 996 is another advantage. Important also is the virtual elimination of fire hazard.

Preliminary testing of Silicone insulated transformers indicates that by proper design, performance characteristics can be kept within the limits specified for larger and heavier transformers built with conventional materials.

Recommended procedures for applying DC 996 are available in leaflet No. A 3-1.

SILICONE GREASES—Essential to the higher operating temperatures made possible by Silicone insulation, and for bearings of machinery in hot locations are high temperature silicone greases. One application of DC 44 was effective for 5¼ months of continuous operation at 125° C. (257° F.) in the bearings of a 7½ h.p., 1750 r.p.m., 440-volt silicone insulated induction motor. Data Sheet No. A 7-1 contains additional information about Dow Corning Silicone Greases.

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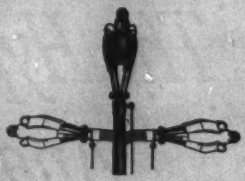

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To remove or replace lamps from side walls or at an angle, pull cord attached to the swivelled ring. This bends the wristlike coil spring so that the Changer will work just as well at a right angle to the rotating pole as in vertical position.

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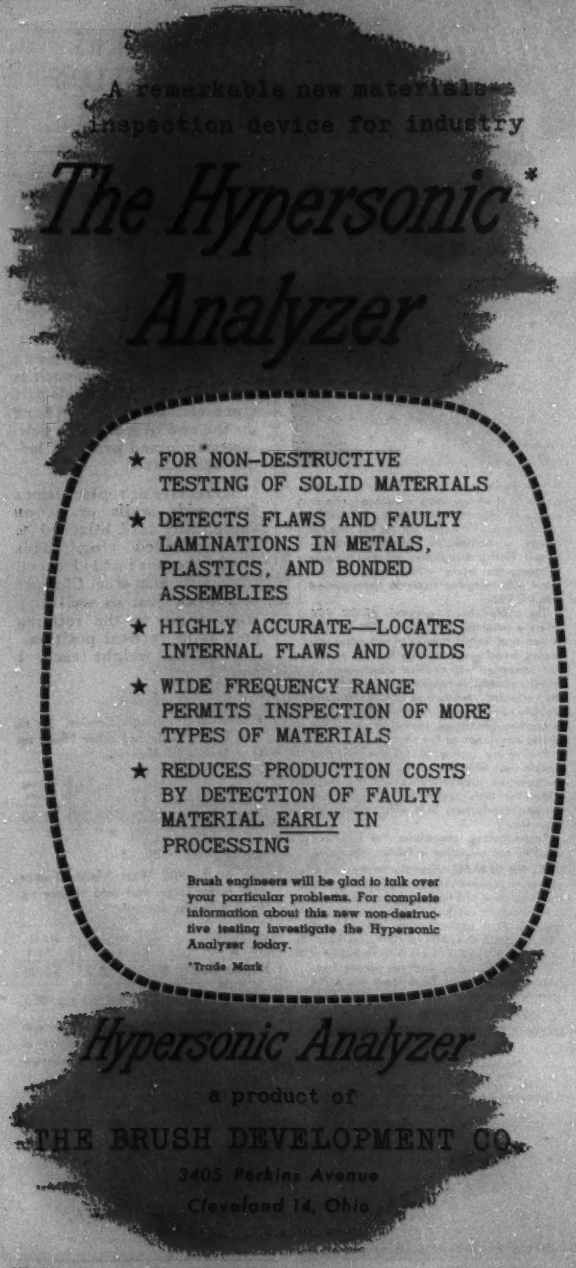
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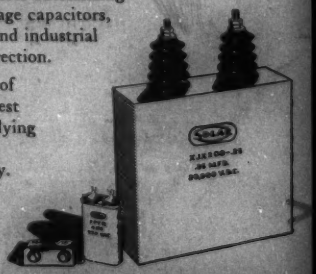

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